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The Effects of Visual Attention on Information Processing in Two-alternative Forced Choice Tasks

A Mouse Tracking Investigation

The Effects of Visual Attention on Information Processing in Two-alternative Forced Choice Tasks: A Mouse Tracking Investigation.

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Abstract

The first part of this thesis investigated the dynamics of visual attention. Traditional performance measures include error rates or response times; however, in this thesis computer mouse tracking was used to provide response times as well as initiation times and response trajectories (including maximum deviation and area under the curve measures). Chapter 2 demonstrated that mouse tracking could be used effectively to replicate previous findings from a simple spatial orientating paradigm (Posner cueing); compared to the use of valid and neutral cues, when invalid cues were presented participants performance declined. Additionally, the analysis demonstrated that neutral cues resulted in increased hesitation at the start of each trial. Chapter 3 demonstrated that mouse tracking in conjunction visual search tasks could replicate previous findings that the inclusion of distractors decreased participants ability to discriminate the orientation of a target; and that the location of the target affected response trajectories. Chapter 4 investigated the role of manipulating the number of targets and cues in an orientation discrimination task. It was found that whilst increasing targets improved participants ability at target discrimination, cues were largely ignored. In order to investigate whether this was due to potential hemifield effects in the design, Chapter 5 demonstrated that a separate hemifield advantage existed only in tasks without distractors. The second part of thesis explored research that claimed movement could influence cognition. However, Chapters 6 demonstrated that it was difficult to replicate these findings and Chapter 7 demonstrated through the use of mouse tracking analysis that previous findings most likely resulted from the mere exposure effect. The overarching conclusion is that mouse tracking provides an easy low-cost methodology that is able to provide valuable information on low level cognitive processes.

Dedication

To my wonderful Dad, a real character and a true gentleman, without your kindness and support this would not have been possible.

Acknowledgments.

I wish to thank my supervisor Chris Kent, for not only his continued academic support but his continued pastoral support during my own difficult personal circumstances. His invaluable knowledge, incredibly helpful feedback and advice has ensured my academic development has not suffered. I am grateful to the University of Bristol for providing plenty of opportunities for me to develop as a researcher and pursue my goals of academic research. Finally, thank you to my Mum Pauline, my husband Simon and to all my friends (especially Natalie Pitimson) for all their support and much needed encouragement throughout the entirety of my studies; without which I would not have been able to complete this PhD.

Author’s Declaration

I declare that the work in this dissertation was carried out in accordance with the requirements of the University's *Regulations and Code of Practice for Research Degree Programmes* and that it has not been submitted for any other academic award. Except where indicated by specific reference in the text, the work is the candidate's own work. Work done in collaboration with, or with the assistance of, others, is indicated as such. Any views expressed in the dissertation are those of the author.

SIGNED: DATE: 18/12/19

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Chapter 1 Introduction

This thesis aimed to investigate the dynamics of visual attention; however, rather than using traditional performance measures such as error rates or response times, the thesis focussed on mapping the time course using computer mouse tracking. In order to establish its effectiveness, it was first used in a simple spatial orientating paradigm before being applied to a visual search task whereby participants had to discriminate the orientation of a target. First the role of distractors in visual search discrimination tasks was investigated then second, the role of cues. Finally, mouse tracking was applied to the role of mere exposure effects in a different type of two-alternative forced choice task involving facial preference. By analysing the mouse tracking data, the aim of each experiment was to uncover the online decision-making dynamics as they occur and link them to the relevant underlying cognitive processes.

1.1 Types of Visual Attention

Every day we are confronted with enormous amounts of information but due to limitations in our capacity to process this it is important to select the salient and relevant information. Attention helps us process the information we receive by enabling us to focus on relevant features. Visual attention specifically refers to the process of filtering information we receive from the visual environment. Visual attention specifically refers to the process of selecting information we receive from the visual environment to prepare for actions such as locating an object (Allport, 1987).

There are three main types of visual attention (Carrasco, 2011). First, spatial attention, in order to direct attention to a specific location it is possible to shift focus; this can be done either overtly and gaze is directed towards a specific location through eye movements; or covertly where gaze is centrally fixed, but attention is drawn to a location in the periphery (Posner, 1980). Second, feature-based attention whereby covert attention is guided to a specific aspect of an object such as colour or orientation and is important when searching for a specific item amongst items with similar features (Carrasco, 2011; Theeuwes, 2013). Third, object-based attention whereby attention is guided by a specific object or a specific structure and location within a selected object (whilst this is not the focus of this thesis, see reviews by Olson, 2001, and Scholl, 2002)

Covert attention enables the visual environment to be monitored and allows eye movements (overt attention) to be moved to locations where pertinent information is held. Behavioural evidence suggests that there are two ways covert attention operates (Posner, 1980; Carrasco, 2011). **Exogenous attention** or transient attention refers to bottom up processes whereby objects or cues can capture attention involuntarily and automatically by being more visually salient. Whereas **endogenous attention** or sustained attention refers to top down processes and attention is wilfully moved to a location voluntarily and is generally seen in goal orientated tasks. Whilst it takes approximately 300 ms to implement endogenous attention which is then sustained for as long as is needed to perform the task, exogenous attention is faster and peaks at 100 ms but deployment decays quickly (Cheal & Lyon, 1991, Carrasco, Giordano, & McElree, 2004).

1.2 Methods of studying visual attention

How attention has influenced behaviour has advanced over the last 40 years due to improvements in the various methods of investigation such as neuro-imaging studies, neurophysiological studies, advances in eye-tracking technology and psychophysical paradigms (Carassco, 2011). This thesis will focus on the latter.

Posner Cueing Paradigm. One of the most influential psychophysical methodologies used to investigate endogenous and exogenous attention in the visual field is the Spatial Orientating Paradigm (Posner, 1980), usually accredited to Posner and his colleagues and sometimes known as the Posner Cue Paradigm or Costs and Benefits paradigm. A typical paradigm usually involves three features (Wright & Ward, 2008). First, a central fixation point, which a participant must focus on throughout the experimental trial. Second, a target item which a participant must identify or locate. Third, a spatial cue to direct spatial attention to the location of a target in the visual field.

A typical sequence of the paradigm (Wright & Ward, 2008; Chica, Bartolommeo, & Lupianez, 2013; Chica, Martin-Arevalo, Botta & Lupianez, 2014), involves participants initially being presented with a fixation cross and placeholder (squared box) for around 1,000 ms. The first stimulus presented is usually an attentional cue which indicates the location of the target. As shown in Figure 1, this can be horizontal cue, an arrow or a change in luminance of the placeholder (a darker squared box). After a short interval (for example, 100 ms as shown in Figure 1), the target is displayed either above the cue or within one of the placeholder boxes. The time between the onset of the cue and the onset of the target is typically referred to as Stimulus Onset Asynchrony (SOA). SOA's are typically less than 200 ms. This is because durations longer than 220 ms are deemed to be long enough for a participant to have enough time to make a saccade to the cued location before the target appears. If this was to occur, it is possible that overt attention may be responsible for the cueing effects and not only covert attention. In target detection tasks, participants are asked to identify the existence of the target. In target discrimination tasks participants are asked to determine a targets colour, orientation or motion direction. In either task participants must respond as quickly as possible, usually by pressing a button. After the response has been detected or the trial has timed-out an inter-trial interval is displayed whereby the screen remains empty for around 1,000 ms.

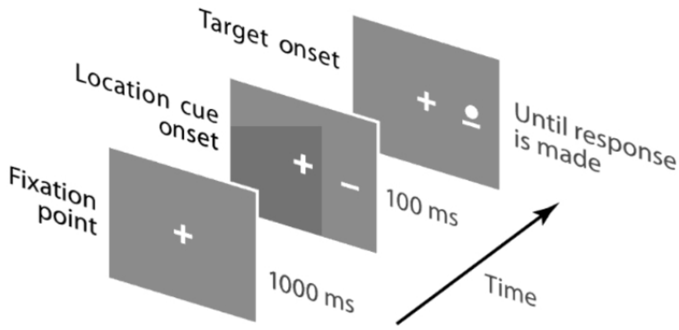


Figure 1.1. Typical spatial orientation paradigm to study the effects of directing attention to aid target detection and identification. A peripheral cue (a horizontal bar) appears on the right-hand side of the fixation point to indicate that a target (circle) is present. Taken from Wright, R. D., & Ward, L. M. (2008). *Orienting of Attention*. Oxford University Press.

In the paradigm attentional cues can be manipulated; cues can be valid, invalid or neutral. When cues are presented at the location of the target, they are valid cues. However, if they appear at a different location to the target, they are invalid cues. Posner (1980) manipulated the probability that a valid or invalid cue would appear. In a given trial, a valid cue/cued location would appear 80% of the time and invalid cue/un-cued location would appear 20% of the time. He found participants were faster and more accurate at identifying a target when a valid cue was used compared to invalid cues. Finally, it is also possible to include a neutral cue. A neutral cue is a non-informative cue which indicates a target is about to appear but only indicates a location where the target is not able to be (central location) or all possible target locations. Posner (1980) included neutral cues to provide a baseline to ensure that valid cues were aiding responses (benefit) and invalid cues were inhibiting responses (cost).

The Spatial Orientating Paradigm has been used investigate the two distinct systems of covert attention: endogenous and exogenous attention (Carrasco, Giordano, & McElree, 2004). Traditionally, research involves using endogenous cues such as a line or symbolic cue presented centrally at fixation and is non predictive of location or an exogenous cues presented in the peripheral of the target display adjacent to the relevant target and therefore predictive of the target location (Carrasco & Barbot, 2014). Exogenous peripheral cues have been found to result in faster response times (RTs; Posner, 1980, Posner & Cohen, 1984); increased accuracy (Müller & Rabbitt, 1989, although this has been subsequently disputed by Prinzmetal, McCool & Park, 2005; Kerzel, Zarian, & Souto, 2009). They have also been shown to interrupt responses from endogenous central cues even when they are not relevant (Müller & Rabbitt, 1989).

Whilst it is assumed that the two different cues can incite the two different attention processes, Chica, Martin-Arevalo, Botta and Lupianez (2014) point out the differences in behavioural data may be due to the 1) the type of cue used (peripheral or central), 2) the predictive nature of the cue (spatially predictive or non-predictive) or 3) other perceptual factors such as whether the cue is presented in the same spatial location. Whilst behavioural data suggest that endogenous and exogenous attention produce different effects on information processing suggesting separate systems, it is also worth noting evidence from neuroimaging studies have indicated an overlap in brain regions involved in both types of attention (see Chica, Bartolommeo, & Lupianez, 2013).

Visual search paradigm. Just as visual attention has a role in decision making and preference choice, it can also influence how visual information is processed. One useful paradigm to investigate the role of covert attention and spatial resolution is the visual search paradigm. By manipulating attentional demands on a participant's ability to search for and identify a target it is possible to investigate how visual attention works. In a typical visual search paradigm, participants are asked to identify whether a target is present or absent when presented amongst similar items (distractors). Two standard tasks are used for investigating attention in visual search (Figure 1.2). First, feature search tasks test how easily participants are able to find a target amongst distractors that have different features (a red vertical line amongst red horizontal lines). Second, conjunction search tasks test how easily participants can find a target with two features amongst distractors that share one of these features (red vertical line amongst red horizontal lines and black vertical lines). In the basic paradigm participants are presented with an array of items and asked to identify if the target is present or absent and the RT's and error rates are measured (Wolfe, 1994). As well as target detection, this paradigm has also been used in target discrimination tasks whereby participants are asked to determine a targets colour, orientation or motion direction. Feature search tasks are deemed to be easier than conjunction search tasks as experiments yield faster RTs and lower rates of accuracy (Treisman & Gelade, 1980; Treisman, Sykes, & Gelade, 1977). Increasing the number of distractors is also deemed to affect each task (see Chapter 3 for further details). In feature search tasks, increasing the set size has little effect on RTs however, in conjunction search tasks as set size increases RT increase (Treisman & Gelade, 1980; McElree & Carrasco, 1999).

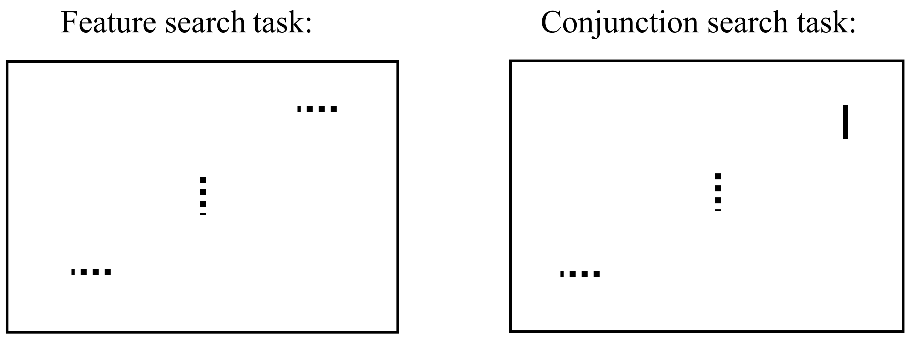


Figure 1.2. Illustration of feature search and conjunction search tasks (due to greyscale the colour red has been illustrated with dotted lines).

Visual search tasks have also been used with cues to investigate the role of spatial covert attention (see Chapter 4 for further details). Carrasco, Evert, Chang, and Katz (1995) asked participants to identify if a target (a red line) was present amongst conjunctive distractors (colour and orientation). Targets were displayed at varying degrees of eccentricities from the fixation point. The authors found that RTs, error rates and the effect of including distractors increased as eccentricity increased. This effect has been found to be eliminated when the target location was preceded by a valid or invalid pre cue (a small horizontal bar) at the periphery of the display in both feature and conjunction search tasks (Carrasco & Yeshurun, 1998).

Visual search tasks have also been used to investigate feature-based attention whereby attention is guided to a specific aspect of an object and is especially important when searching for a specific item amongst items with similar features. Although most of the research on feature-based attention has involved signal-unit recordings, and neurophysiological studies (Gallant, Shoup & Mazer, 2000; Bichot, Rossi & Desimone, 2005). It has been suggested that in order to guide attention, it is useful to think of attributes that could guide the deployment of attention (Wolfe & Horowitz, 2004). For example, in feature-based searching, in identifying a horizontal target, priority should be given to the undoubted attribute horizontal orientation; in conjunction-based searching for a red horizontal target, priority should be given to the undoubted attributes the red colour and horizontal orientation. However, Shih and Sperling (1996) asked participants to identify a series of targets (numbers) amongst a distractor set which varied on two dimensions (colour and size) and manipulated pre-attention to features by including instructions such as 'attend to large characters', presentation probabilities (probability of the feature appearing) and payoffs (running accuracy score which resulted in potential payment). The authors found attending to features (red or large) did not improve finding a target accurately. However, in a second experiment they tested whether features can guide attention to a spatial location (rather than a specific object). They used the exact same experimental paradigm but a different target identification task. Participants had to identify a target that was the odd item out of a display of six items. This meant unlike their first experiment, where filtering out items that were not required would make the task easier, in this task filtering out irrelevant items could make the task harder as it would be harder to identify the odd item. The cues were aimed to direct attention to the location of the target item. The authors found that directing attention to the target location aided detection and misdirecting attention hindered target detection.

1.3 Measures of information processing

Typical measures. Psychophysical methods such as the spatial orientating paradigm and visual search paradigms, rely on two dependent measures: RT and accuracy. It is assumed that faster RTs and less errors reflect greater performance at the task. However, a single measure of RT does not demonstrate how information is accumulated over time and it can become confounded by the speed-accuracy trade off where greater speeds come at the cost of greater errors and slower speeds result in fewer errors. Whilst ideally, the participant tries to maximise performance by offsetting speed and accuracy it is not always possible to determine where along the speed-accuracy trade-off continuum a participant is responding.

In order to address these issues, many psychophysical studies use a response-signal speed–accuracy trade-off (SAT) paradigm (McElree & Dosher 1989, Wickelgren 1977). This method involves specifying when a participant may respond. On each trial, a response signal such as a tone indicates that the participants must respond. By manipulating when the signal/response occurs and measuring accuracy researchers are able to plot accuracy as a function of time, producing a SAT curve for each given experimental condition. Generally, during the early intervals' accuracy is closer to chance and during the later intervals, increasing time does not increase accuracy and it reaches asymptotic levels (Liu & Watanabe 2012).

Once the SAT curve has been produced, to measure task performance generally an exponential function is fitted to the data:

$$d(t) = \lambda\left(1 - e^{-\beta(t-\delta)}\right)$$

in which λ is the (asymptotic) level of accuracy/discriminability, β is rate at which discrimination improves (information accumulates) and δ is the intercept which reflects any non-processing time such as motor movement RT (e.g., Kent, Guest, Adelman, & Lamberts, 2014). By analysing differences in the SAT function such as lower asymptotes or faster rates, it is possible to compare how accuracy and processing rates differ between conditions.

The SAT paradigm has successfully been applied to the visual search paradigm and used to investigate the influence of attention on discrimination and the rate of visual information processing. In particular it has been applied to differences in performances between feature search tasks and conjunction search tasks which had initially been deemed to represent different theoretical processes (discussed further in the next section).

1.4 Theoretical background: Overview

The role of visual attention in visual search. In the past 30 years, there has been considerable interest in the role of the mechanisms that underlie visual attention. Differences between feature search tasks and conjunction search tasks have been argued to demonstrate different mechanisms underlying the detection of features and conjunctions of features (Wolfe, 1994; McElree & Carrasco, 1999). Specifically, it has been applied to the debate of whether information is processed all items at once (parallel processing) or whether visual attention selects information one item at a time (serial processing). One of the most influential theories is Treisman's Feature Integration Theory (FIT). Treisman and Gelade (1980) proposed two distinct stages of visual search; first an early pre-attentive stage whereby single primitive features from the visual field such as colour or shapes are processed in parallel without integration. In this pre-attentive stage, a single feature in the visual field, for example a target red line amongst black lines distractors are said to 'pop out' and not require attention. It is suggested that increasing the number of distractors in feature search tasks does not impair target location because the feature is unique to the environment so increasing the number of distractors does not have an impact on participants' ability to locate the target. It is this 'pop out' feature which is said to be main characteristic of parallel processing. A second stage occurs when a parallel search is not possible, and attention is required to bind the features in the visual environment together serially (one at a time). In conjunction search tasks, where a target shares two features with distractors in order to find the target feature integration is required and processing must occur serially. Treisman's theory has further been supported by psychophysical evidence which has demonstrate that feature search tasks are associated with shorter RTs and lower error rates. Whereas when the tasks become more complex, such as in conjunction search tasks, longer RTs and higher error rates are taken as evidence that visual attention occurs serially. This will be discussed in further detail in Chapter 3.

However, subsequent studies have shown that these distinct processes are not as clear cut as initially proposed and conjunction search tasks can be accomplished using parallel processes. For example, Nakayama and Silverman (1986) used a variety of conjunction search tasks involving motion and colour. In the first conjunction search task blue distractors moved down and red distractors moved up whereas the target broke this pattern, a blue target moved up and red target moved down. By using a 3D visual display, they created a conjunction search task using stereo and motion, distractors at the front moved up and distractors at back moved down and the target was either at the front moving down or at the back moving up. The final conjunction search task using stereo and colour, distractors at the front were blue and distractors at back were red and the target was either red at the front or blue in the back. Given that these were conjunction search tasks the target should not 'pop out' however there was no increase in RT's with increasing set sizes. Participants also reported that they scanned each depth in turn to locate the target (Nakayama & Martini, 2011) which would suggest that neither was this a pre-attentive task. It has also been shown that attention can actually affect pre-attentive tasks such as acuity and texture segmentation tasks (Carrasco, Williams & Yeshurun, 2002, Yeshurun, Montagna & Carrasco, 2008; Carassco, 2011).

As the parallel/serial viewpoint has been questioned alternative two stage models have been proposed. For example, the Guided Search Model (Wolfe, 1994) originally proposed by Wolfe, Cave, and Franzel (1989) this model had a pre-attentive stage where basic visual features of stimuli are processed which then feeds into and acts as a guide to the second attentive stage where more complex task driven processes occurs. It suggests differences in visual search tasks result from differences in the quality of guidance. Bottom up guidance depends on the stimuli presented such as similarity between objects in a search display whereas top down guidance depends on task driven factors such as the similarity between a specific target and the search display. Now in its 4th version (Wolfe & Gray, 2007) this model suggests visual information is processed initially in parallel which subsequently guides object recognition via a mandatory bottleneck. Selective attention plays an important role in selecting which objects will be recognised and can affect performance on visual search tasks when searching for an object amongst distractors. Wolfe (1998) suggests that the parallel/serial dichotomy is better described as searches which are either efficient or inefficient.

Another alternative approach to visual search is to produce a single stage model of decision making (Duncan & Humphreys, 1989; Verghese, 2001; Cameron, Tai, Eckstein & Carrasco, 2004). Based on signal detection theory (Palmer, Verghese & Paval, 2000), rather than assuming a two-stage process, these models propose processing occurs in parallel until a decision-making threshold is reached. For example, Similarity Theory (Duncan & Humphreys, 1989) suggest differences between feature and conjunction search tasks are explained on the basis of grouping items together in the visual field and matching these items to a template stored in memory. Grouping is deemed to occur in parallel before competition of items occurs between the template and non-matching items. An item gains weight when it matches the template and is subsequently chosen. Rather than different processes occurring in different tasks the same operations occur, however, matching to a template becomes more difficult as similarity increases between the target and the distractor.

Alternatively, rather than being based on stimulus sampling other models are based on sequential sampling (Luce, 1986). These models assume participants accumulate information from a sample until enough evidence has been gathered for a definitive response (Kent et al., 2014). Based on Ratcliff's Drift Diffusion Model (1978), Krajbich, Armel and Rangel (2010) presented the attentional Drift Diffusion Model (aDDM) of decision making to include the role of visual attention on binary choice. The model assumes that a decision value known as the relative decision value (RDV) is computed; before each trial the RDV starts at 0 but is continuously integrated and recomputed over time until it reaches a threshold of either +1 (left item is chosen) or -1 (right item is chosen). Generally, these models are dependent on two factors: the quality of the information provided in a task, and the quantity of information sampled by the participant (Ratcliff & Smith, 2004). This is particularly useful in accounting for the speed-accuracy trade-off relationship described earlier, for example faster RTs can be achieved by reducing the threshold, but because less evidence has been accumulated, more errors are likely to be made.

Overall the distinction between pre-attentive and attentive stages has waned, the parallel/serial dichotomy is no longer strictly part of FIT (Wolfe, 1998) and instead current theories often focus on modelling how information is sampled from the visual environment (Guest & Lamberts, 2011).

The role of visual attention and mere exposure effects. When choosing between two alternatives individuals shift attention between the different options. Increasing visual attention has been found to increase positivity towards an item, through a phenomenon known as the ‘mere exposure effect’. Mere exposure effects have been defined as an increased preference towards a stimulus as a result of being repeatedly exposed to that stimuli (Zajonc, 1968). The typical paradigm involves showing participants a set of stimuli and varying the number of times the stimuli appears. At the end of the task participants are either asked to provide a liking rating for these stimuli or choose the option they prefer. In general, participants are more likely to prefer stimuli that they were exposed to more frequently.

There has been some debate as to how increasing visual attention and awareness impacts the mere exposure effect. Bornstein’s (1989) meta review of research found that the mere exposure effect could occur for stimuli presented below a recognition threshold, and that larger effects of mere exposure were found when participants were not aware of the stimuli. Whereas more recent research has found mere exposure effects do not occur without conscious awareness (de Zilva, Vu, Newell, & Pearson, 2013). De Zilva et al. (2013) asked participants to rate the pleasantness of contour lines and faces. Using a technique known as continuous flash suppression stimuli are presented to one eye whilst visual noise is continuously flashed to the other eye competing and dominating with the original stimuli so that the participant is not consciously aware of it. The results demonstrated that when participants were not consciously aware of seeing the contour lines or the faces there were no mere exposure effect. Furthermore, when facial stimuli were presented, if participants were aware of seeing the faces the mere exposure effect was found.

As a result of this research several accounts have been proposed to explain why the mere exposure effects occurs. Zajonc's Affective Model (1968) suggests that people evolved to be wary of novel stimulus and repeated exposures produces a positive emotional response. The Two-factor model (Berlyne 1970; Stang 1973) suggests positive evaluation occurs because of greater familiarity and reduced uncertainty, however, too much exposure can increase amounts of boredom. One of the most widely regarded is the Perceptual Fluency Theory (Bornstein & D'Agostino, 1992, 1994) whereby repeated exposure to neutral stimuli enhances processing ease, speed, and 'fluency' of perception. This ease of processing is misattributed to liking. However, subsequent experiments have challenged familiarity, ease of recognition or perceptual fluency as an explanation (Zajonc 2001).

Monahan, Murphy, and Zajonc (2000) presented participants with neutral stimuli of either Chinese ideographs or polygons. They either viewed 25 stimuli or 5 stimuli repeated 5 times. All were presented 'subliminally' for 5 ms. After the initial exposure phase participants were exposed to 15 test stimuli, 5 had already been shown (old) 5 were similar to those shown in the initial phase (novel but similar) and 5 were completely different stimuli (novel and different). Participants then took part in a liking trial and rated the stimuli on a scale of 1 to 5. It was found that participants who experienced 5 repetitions of each 5 stimuli rated all the stimuli in the subsequent liking task more positively than those who initially viewed 25 stimuli. The authors concluded that the positive affect from repeated exposures could, therefore, even occur with stimuli not seen and unfamiliar stimuli. This is inconsistent with the perceptual fluency account whereby only previously exposed stimuli should be viewed more favourably.

Zajonc et al. (2001) suggest instead that mere exposure results as a result of a unique form of conditioning. In the classic paradigm Pavlov (1927), the conditioned stimulus (bell) is followed shortly by an unconditional stimulus (food). This is repeated together until eventually an unconditioned response (salivation) occurs at the presentation of the conditioned stimulus (bell) alone. In the mere exposure paradigm, the repeatedly exposed stimulus is viewed as the conditioned stimulus. However, uniquely it is not followed by any positive or negative consequence as there is no unconditioned stimulus. Zajonc (2001) argues that the lack of negative consequence is in itself a positive experience and an unconditioned stimulus. Unusual stimuli would therefore be viewed tentatively but previous seen stimuli would be viewed as safe. Thus, in Monahan et al.'s (2000) experiment repeatedly exposing participants to 5 ideographs allowed participants to view all subsequent stimuli as more positive than those viewed 25 different ones. However, to date there is still not one comprehensive theory of the mere exposure findings.

There has also been interest in understanding the decision-making process and producing a model which can explain the mere exposure phenomenon. Similar to visual search tasks the majority of models are based on sequential sampling and the idea that we accumulate evidence until a threshold is reached (see Ratcliff & Smith 2004, for a review). Krajbich, Armel, and Rangel's (2010) aDDM of decision making has also been applied to the literature surrounding mere exposure effects. The model makes several predictions about how visual attention influences the RDV. For example, it predicts that visual attention increases the RDV when appetitive items are viewed and decreases the RDV when aversive items are viewed. Consistent with an embodied cognition viewpoint, described in the next section, the model suggests that it is possible to change the RDV assigned to a stimulus exogenously by manipulating visual attention (Armel, Beaumel & Rangel 2008).

1.5 Alternative methodologies: Mouse tracking

Whilst measures such as RTs and accuracy rates, can provide important data, they are only able to depict the end state of a process and cannot track on-line response dynamics as they unfold over time. Subsequently alternative measures have been used; such as eye movements, however these are still ballistic to a degree, or neuro-imaging techniques which can measure brain activity in milliseconds but are expensive to run. Response-signal SAT procedures have become a common paradigm in visual search research, but they also have a few limitations. First, it is an unnatural format, limiting when you respond to a response tone is peculiar to most participants. Second, to train participants to respond at a tone and within a reasonable timeframe on hearing the tone involves many practice trials. Third, participants have to monitor for a signal and prepare a response, this creates a secondary cognitive load which may confound the speed/accuracy measurements. Finally, by prompting participants to respond when they are not ready does mean a response is not always given and data is lost.

An alternative to using the SAT procedure is to record response trajectories made by mouse movements (for a brief review, see Kent, Taylor, Taylor & Darley, 2017). The advantages of using mouse tracking is first, participants find it natural and easy to use mouse to respond to a decision. Second, no practice trials are required as participants are familiar and able to use the computer mouse to respond. Third, using a computer mouse places no secondary load on the participants. Fourth, whilst there is some loss of data, if participants do not move their mouse as soon as the trial initiates, this loss of data is minimal.

Traditionally cognitive psychologists have regarded motor responses as distinct and separate processes and consequently it has been neglected by experimental research (Rosenbaum, 2005). However, there is a growing number of studies that demonstrate that there is link between cognition and action, and motor responses may not just reflect the end state of a cognitive process but demonstrate our cognitive state as it occurs (Freeman, Dale, & Farmer, 2011). Spivey, Richardson, and Dale (2009) review a number of studies that demonstrate cognitive processes are part of the cognitive system. For example, Tse and Cavanagh (2000) presented participants with animation of Chinese characters being produced stroke by stroke. Whilst each line appeared at once, participants were able to perceive the direction of the stroke. American participants used bottom up cues to determine the motion of each stroke. Whereas participants from China overrode the bottom up cues and used top down processing, assuming the strokes occurred in the direction as if they had drawn it by hand. This study demonstrates how knowledge of movement can influence perception.

Knoblich and Flach (2001) recorded participants throwing darts at a dartboard. From viewing footage of the dynamics of the arm movement alone, participants were asked to predict the location the dart landed. The findings demonstrated participants were more accurate at anticipating the correct location when watching themselves compared to watching others. This study demonstrated that we are able to use motor systems to predict perceptual events.

Neurophysiological evidence has also demonstrated that our own motor experience can influence cognition. Calvo-Merino, Glaser, Grèzes, Passingham, and Haggard, (2004) ran an fMRI study to compare the brain activity of professional dancers when they watched their own style of dancing compared to another styles. When watching their own style participants activated the premotor cortex. The authors concluded that they could cognitively generate their own motor simulation.

Movement has also been shown to work in parallel with our cognitive processes and continually update. For example, Goodale, Pelisson, and Prablanc (1986) asked participants to move their finger towards a target (LED light) which moved from a central position to a peripheral one. For half the trials the target moved once but in the other half of trials the target made a second step and moved further away. The second step occurred as participants started to reach for the initial target. Although participants were not able to view their hand in relation to the target the authors found that participants automatically adjusted their trajectory, thus hand movements were altered by feedback from the task environment.

As a result of such research many researchers such as Spivey, et al. (2009) and Freeman, Dale, and Farmer (2011) have concluded that by measuring action it is not only possible to measure cognition, but it is possible to manipulate cognition.

The use of movement as a measure of cognition has already been successfully used in cognitive psychology. For example, Welsh and Elliott (2004) asked participants to identify a target (red LED light) from amongst distractors (green LED light) displayed on a wooden mounting board. Reaching trajectories were measured from recording an infrared guitar pick. The presence of distractors caused movements to deviate towards the distractors. Participants initiated each trial by pressing a button nearest them, this was also known as the home position. Movements were longer and higher when the distractors were located further away from the home position than the target, compared with when the distractor was located closest to the home position than the target. The longer movement trajectories revealed when distractors were presented beyond the target participants were drawn to the distractors. The height of the movements when the distractor was presented before the target suggest that the distractor was not seen as an object to be avoided.

In a series of experiments, Buetti and Kerzel (2009) analysed hand reaching in relation to the Simon task. In the Simon task, participants are asked to respond in a certain direction to a visual stimulus, such as move right when presented with a circle and move left when presented with a square. The location the stimuli is displayed either matches the expected direction or is incongruent to the expected direction. Single point measures such as RTs and error rates are longer for conflicting incongruent trials compared with congruent ones. By plotting movements as a function of RTs, the authors were able to demonstrate that longer RTs occurred as a result of participants moving towards the incorrect response before correcting themselves. Whilst increasing time pressures on participants impacted RTs it did not impact movement parameters.

With the development of technology, motor responses can now be recorded from the use of a computer mouse. Whilst it is possible within most programming languages to record mouse position over time, there is also pre-developed software such as MouseTracker available (Freeman & Ambady, 2010). The MouseTracker program (Freeman & Ambady, 2010) is a freely available experiment builder that allows for recording RTs, response choices, and can record the x and y co-ordinates of the computer mouse. A typical two forced choice alternative mouse tracking experiment involves the participant initiating each trial by clicking a 'start' button. Although it can be placed anywhere the 'start' button is usually located in the bottom centre of the screen and centralises the mouse movements before each trial. The stimulus relating to the choice task are presented and participants are encouraged to start moving their mouse as soon as possible; this enables responses to be recorded from the onset. In order to provide the longest possible response trajectory, response buttons are located in the top left or top right of the screen. The trial end either when a participant clicks a response or after a predetermined 'time out' duration.

Once completed, this methodology is able to provide a variety of descriptive analyses. First, mouse trajectories, from a single mouse trajectory for each 13-16 ms (depending on refresh rates) it is possible to record fan x-coordinate and y-coordinate in pixels (Freeman & Ambady, 2010). Due to individual variation in the trajectory lengths, it is necessary for these to be normalised. Typically, this is done by linear interpolation into 101 time bins. Each time bin then has a corresponding x- and y- coordinate. This means despite different RTs and different trajectory lengths can be averaged and compared between trials and conditions. Also, to aid comparison the direction of the trajectory can be transposed so that all trajectories follow the same direction it therefore does not matter which side of the screen the response button was located, and a direct comparison between conditions can be made.

In conjunction with the trajectory the corresponding Area Under the Curve (AUC) and Maximum Deviation can be recorded. To calculate AUC the area between an imaginary trajectory extending from the starting x- and y- coordinates to the final x- and y- coordinates and the actual trajectory is calculated, as shown in Figure 1.3. Maximum deviation is simply the largest perpendicular distance between the imaginary trajectory and the actual response trajectory. Higher AUC and higher MD reflect deviations which are further away from a direct trajectory, which represents deviation toward the alternative response. In addition to these measures, discrete variables such as RT, initiation time (how soon participant moves the mouse at the start of a trial), x and y flips (number of times a hand trajectory reverses along the x or y axis deemed to illustrate uncertainty in a trial) are collected.

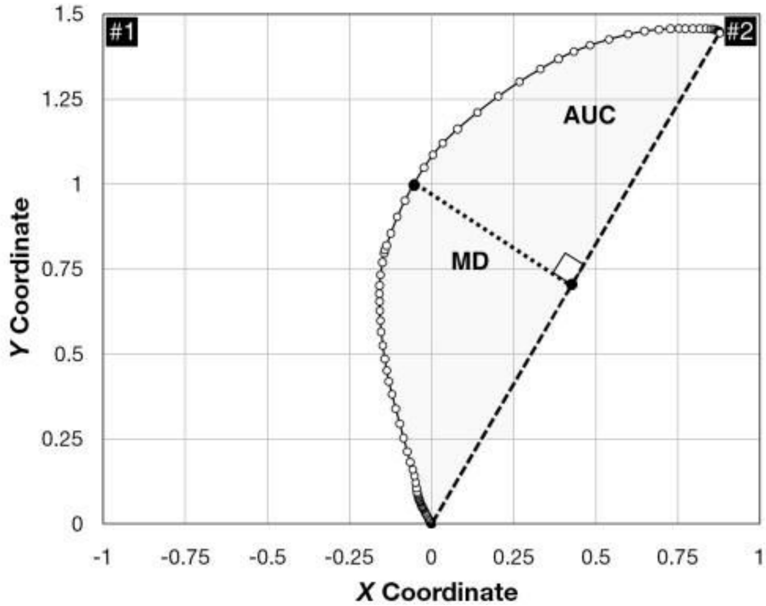


Figure 1.3. Diagram of the MouseTracker co-ordinate space and imaginary trajectory drawn in order to calculate maximum deviation (MD) and area under the curve (AUC). Taken from Freeman, J. B., & Ambady, N. (2010). MouseTracker: Software for studying real-time mental processing using a computer mouse-tracking method. *Behavior Research Methods*, 42, 229.

MouseTracker has already been successfully applied to a wide range of areas in psychology and was initially used in linguistical research. For example Spivey, Grosjean, and Knoblich (2005) asked participants to listen to a spoken word and identify the corresponding item. Target items were presented with one distractor alternative which sounded phonetically similar to the word heard (e.g. 'candy' and 'candle'). The words were displayed pictorially in the top corners of the screen. Once the participants had listened to the word they had to click on the corresponding picture. The authors found that the computer mouse moved towards the incorrect item before a correct item was chosen. Incera and McLennan (2016) used mouse tracking in conjunction with a Stroop task to compare the abilities of bilingual and monolinguals. The Stroop phenomenon refers to difficulty participants experience when attempting to identify the colour of a word when a word of a different colour is used. Whilst some studies show that RTs are faster for bilingual participants in comparison to monolinguals, others have failed to replicate the finding. It was found that bilinguals took longer to initiate a response but then moved faster towards the correct answer compared to monolinguals which could account for contradictory evidence from studies solely looking at RTs.

It has since been applied to a variety of cognitive areas such as categorisation. For example, Dale, Kehoe, and Spivey (2007) asked participants to categorise stimuli (words or pictures) into two categories (Mammal or Fish). The stimulus set consisted of examples which were either typical examples (cat) or atypical (whale). By recording the mouse movement trajectories, it was found typical examples produced trajectories that were more direct, whereas atypical examples produced trajectories that showed attraction towards the competing category. The authors concluded these mouse trajectories demonstrated a graded response whereby participants also accumulate information for the alternative category.

In the perception of race, Freeman, Pauker, Apfelbaum & Ambady (2010) used MouseTracker to investigate the temporal dynamics of race categorisation. Participants were asked to categorise White and Black faces. In the first experiment computer generated faces which had been morphed to be either typical or atypical were used. The authors found that participants' hand movements demonstrated a continuous attraction towards the opposite-race category when a race-atypical face was presented. In the second experiment real faces that had varying degrees of racial ambiguity were presented and from analysing trajectory movement the authors found a graded attraction towards the opposite-race category. They concluded that when perceiving race atypical faces trigger competing race-category representations simultaneously and that as ambiguity increases so does the competition between the race categories.

In memory research, Papesh and Goldinger (2012) used MouseTracker to investigate recognition memory. Participants were asked to memorise a series of words, after a brief anagram task, participants had to judge a second series of words as being old or new by clicking response buttons in the top corners of the screen. Following each recognition decision participants verbally gave a confidence score of their response. By recording hand trajectories, it was shown that high confidence levels were associated with shorter RT's and more linear response trajectories. It was also found that regardless of accuracy old responses had a stronger correspondence to mouse movements compared to new responses suggesting that there is a link between memory, feelings of confidence, and motor movements.

In the decision-making literature, McKinstry, Dale, and Spivey (2008) used mouse tracking to investigate a participant's perception of truth to a variety questions such as 'Should you brush your teeth every day' or 'Is the sky ever green?'. Response buttons of 'Yes' or 'No' were placed in the top hand corners of the screen and mouse trajectories were recorded. Larger hand trajectories and broader distributions associated with 'No' responses indicated that regarding a statement as false occurred with more difficulty than if it was evaluated as true.

As shown in these examples, mouse tracking has been used to trace the time course of perceptual and cognitive function in a wide range of psychological areas and has helped to provide further information into the relevant underlying mechanisms. Therefore, it is possible that recording mouse trajectories could also provide a potential low-cost methodology in which to investigate other areas of, lower levels, of cognitive psychology such as visual attention and the mere exposure effect.

1.6 Summary of Empirical Chapters

This thesis will apply the mouse tracking methodology to these two different areas of psychology. The first part of this thesis will investigate how mouse tracking can be applied to the Posner Cueing Paradigm before it is used to investigate how increasing the number of distractors in the visual field and manipulating covert attention through cueing, affects performance in visual search tasks. The second part of this thesis will explore research which claimed manipulating eye movements could alter preferences and mouse tracking will be used to investigate the research which has subsequently explained these findings through mere exposure effects.

1.6.1 Chapter 2. Using MouseTracker to replicate the Posner paradigm

Chapter 2 introduces the mouse tracking paradigm and is used to complete a simple replication of the Posner paradigm. In addition to the traditional measure of RT's further examination of the variety of measures available with mouse tracking is detailed. Whilst the RT's indicate participants moved fastest with a valid cue and slowest with an invalid cue; performance with neutral cues were similar to trials with an invalid cue. The additional mouse tracking measurements demonstrated the longer RT's in the neutral condition were a result of participants hesitating at the start of the trial and response trajectory performance was actually similar to those in the valid cue condition.

1.6.2 Chapter 3. Mouse tracking and visual processing with distractors

Having successfully applied the mouse tracking paradigm to the Posner paradigm it was then applied to early attention mechanisms in the form of target discrimination tasks. Typically investigated using the speed-accuracy trade off paradigm, it has been found that task performance is harder when distractors are present. In addition to the typical measurements of increased RT's and error rates found in previous studies, mouse tracking was also able to provide additional corroborating measurements of increased curvatures of response trajectories, larger maximum deviations and areas under the curve.

1.6.3 Chapter 4. Mouse tracking and visual processing with cues

This chapter continued investigating the role of visual attention by using mouse tracking to investigate participants performance on target discrimination when first, the number of targets and distractors were manipulated and second, the number of cues were manipulated. The results demonstrated that increasing the number of targets aided performance. Whilst overall participants appeared to ignore cues, improvements were seen in the four-target condition when the number of cues increased from one/two cues to three/four cues.

1.6.4 Chapter 5. Hemifield effects in visual discrimination tasks

As the results in Chapter 4 demonstrated differences in mouse tracking trajectories between one/two cues and three/four cues this chapter explored whether presenting cues or targets on the same or different sides of the visual field affected visual search efficiency. The data from Experiment 4 whereby distractors were present was reanalysed and an additional experiment where distractors were absent was conducted. Whilst it was not possible to ascertain any hemifield effects from the reanalysis, mouse tracking was able to demonstrate a hemifield advantage for bilateral stimuli when distractors were absent.

1.6.5 Chapter 6. A replication of gaze manipulation and preference

The second part of the thesis explored whether manipulating movement could impact cognition. This chapter attempted to replicate the finding by Shimojo, Simion, Shimojo and Scheier (2003) that manipulating eye gaze could influence preference. The first experiment failed to replicate the findings. In a second experiment using different facial stimuli, it was found that increasing stimuli duration of facial stimuli had a small but significant influence on preference. The chapter concluded the change in preference was not a result of manipulating eye gaze but the result of the mere exposure hypothesis.

1.6.6 Chapter 7. Mouse tracking duration and repetition effects on preferences

The final chapter assessed whether it was possible to use mouse tracking to investigate how increasing duration of facial stimuli influenced preference. Consistent with previous findings, duration had a small but significant influence on preference. Whilst no differences were found in the mouse tracking data the mouse tracking paradigm allowed for a large number of participants to be tested.

1.7 Participation

In all experiments ethical approval was granted by the University of Bristol, Faculty of Life Sciences Research Ethics Committee. All participants reported normal or corrected-to-normal vision and gave written informed consent. The number of participants included in Chapters 2-6 were based on numbers used in similar experiments established in the literature, whereas in the two experiments in Chapter 7 a priori power analysis was conducted and is reported in the relevant method sections (7.3 and 7.5).

1.8 Apparatus

Experiments were either conducted in MouseTracker (Freeman & Ambady, 2010) or MATLAB 2012a, with the Psychophysics Toolbox extension (Brainard, 1997; Pelli, 1997; Kleiner, Brainard, & Pelli, 2007).

Due to the within subject design of the experiments and the use of group testing viewing distance was not standardised (although participants sat approximately 50cm from screen). Pixels have been reported throughout the thesis, when the 15.4” 1,280 x 800 pixel laptop was used 100 pixels were the equivalent of approximately 2.95 degrees of visual angle. When the 21” 1,920 x 1,200 pixel computer monitor was used 100 pixels were the equivalent of approximately 1.43 degrees of visual angle.

Chapter 2 Using MouseTracker to replicate the Posner paradigm

2.1 Chapter summary

MouseTracker provides a potential low-cost methodology in which to study low level visual attention tasks. In order to assess whether it is useful in studying visual attention, this chapter will explore whether it can be used in a simple replication of the Posner paradigm. To explore how orientating attention through the use of a central endogenous symbolic cue affects participants performance at locating a target, a variety of measures will be recorded. In addition to the traditional measurement of RT's which indicated participants moved fastest with a valid cue and slowest with an invalid cue. Further mouse tracking measures indicated that participants were able to respond faster and more directly in the valid cue condition. Whereas in the neutral condition, participants were more hesitant at the start of each trial and in the valid cue conditions participants made more movements towards the incorrect response before selecting the correct response.

2.2 Introduction

As detailed in the Chapter 1 introduction, one of the most influential methodologies used to investigate spatial cueing in visual attention is the Spatial Orientating Paradigm (Posner, 1980). This experiment will focus on using endogenous orientating whereby attention is moved to a location voluntarily based on goal directed behaviour. In order to manipulate endogenous attention, a standard Spatial Orientating experiment uses a central predictive symbolic cue pointing to the target location. This cue can be valid (points towards the target location), neutral (provide no indication of location) or invalid (points towards the opposite side of the target location). As typical examples of the Spatial Orientating Paradigm use arrows, this experiment will also use a central arrow which will be either valid, neutral or invalid. Posner (1980) observed that RT's were shorter when the cue was valid and longest when it was invalid. He concluded that increasing attention through the use of cues improves participants performance as it speeds information processing of targets.

Another common manipulation in the Spatial Orientating Paradigm is the cue frequency probability. Posner (1980) used a ratio of 80:50:20 for valid, neutral and invalid cues, respectively. When a cue pointed to one side the probability of the cue being valid and the target appearing on the cued side was 0.8, and the probability the cue was invalid and the target appeared on the opposite side was 0.2. When a neutral cue was used the target could appear on either side with equal probability. This present experiment will also use the same validity ratio. The Posner cueing paradigm is also known as the cost and benefits paradigm because a valid cue should provide benefit and an invalid cue should come at cost. The inclusion of a neutral cue is useful as it can provide a baseline to ensure that valid cues have aided RT's (benefit) and invalid cues have slowed RT's (cost). It is expected that RT's for neutral cues should be between valid and invalid cues.

Another variable to manipulate is the type of task used. In detection tasks, participants are asked to identify when a target is present. Posner (1980) used a manual detection task and participants were asked to press a button when a target appeared. In discrimination tasks, participants must identify a specific aspect of the target, often orientation. Other spatial orientating experiments have used pointing or reaching tasks. Barthelemy and Boulinguez (2001) used central spatial cues, a directional arrow, which pointed to a target location. Cues were either valid (75%), neutral (50%) or invalid (25%). By measuring participants RT's of pointing to a target they found a validity effect. Valid cues reduced RT's and invalid cues increased RT's.

This experiment will investigate spatial orientating by use a mouse tracking task. Whilst the typical measurement of the Posner (1980) paradigm is RT's they can only depict the end state of the decision-making process and cannot track online response dynamics as they unfold over time. In order to attempt to capture on-line response dynamics and demonstrate that mouse tracking can provide a valuable alternative methodology and measurement, this experiment will use MouseTracker to record RT's. In addition, it will also monitor response movements as they unfold by recording initiation times, response trajectories, corresponding maximum deviations and area under the curve.

In summary, the present experiment will attempt to replicate the findings from an endogenous Spatial Orientating paradigm. A central symbolic cue of an arrow will be presented to participants in three conditions: valid cue, neutral cue and invalid cue condition which differ in frequency at an 80:50:20 ratio respectively. As participants are asked to move their mouse quickly in all conditions, we would not expect a difference in initiation times between cue conditions for such a simple task. However, it is expected that valid cues will result in shorter RT's and direct hand trajectories with a smaller corresponding AUC and MD. In the invalid condition, it would be expected that participants attention will be directed towards the incorrect response so participants will move the computer mouse towards the alternative response before adjusting their hand trajectories to the correct answer. As such invalid cues should result in longer RT's and indirect hand trajectories; correspondingly the

MD and AUC should be larger and potentially have a bimodal distribution. In order to investigate how invalid cues affect participants trajectories and whether they move continuously or if each trajectory combines both linear movements and deviant ones (reflecting changes in mind), it is possible to review the distributions of the data. Freeman and Ambady (2009) suggest that if such a correction takes place then the distribution of the measures should be bimodal. Whilst bimodality is not expected for initiation times, they may appear in the MD and AUC of the invalid condition.

2.3 Methods

Participants. Twelve undergraduate students (9 female) aged between 18 and 23 took part in the experiment. All participants had normal or corrected-to normal vision.

Materials and stimuli. Stimuli were presented on a 21" 1,920 x 1,200 pixel computer with 60 HZ refresh rate. The stimuli were presented in a darkened room. Participants sat approximately 50 cm from the screen and had to move a mouse placed on the right-hand side of a desk to respond.

The MouseTracker space represents a 2 x 1.5 rectangle, the start button and beginnings of all response trajectories is located in the bottom centre of the screen (co-ordinates 960 px, 0 px). One response button (240 px x 384 px) was located in at the top hand side of the screen (co-ordinates 0 px, 1200 px) and the other response button was located at the top right-hand side of the screen (co-ordinates 1536 px, 1920 px).

A fixation point consisted of a single black cross (15 px x 15 px). Each target was a solid black star (116 px x 118 px) which was presented in the top left or right response buttons of the screen in a black square. Each directional cue consisted of a single solid black arrow, 40 pixels in length with an arrowhead 10 pixels wide and 10 pixels high, either pointed to the left or right. The neutral cues consisted of two solid black arrows pointing in either direction, 20 pixels in length with an arrowhead 5 pixels wide by 5 pixels high (shown in Figure 2.1).

Design and Procedure. Participants had to identify which side of the screen a target (a black star) appeared, see Figure 2.1 for a sequence of events. The participants were familiarised with the target before the experiment started in the task instructions. Participants initiated each trial by clicking the START button in the bottom centre of the screen. A fixation cross then appeared for 400 ms before a pre cue of either a valid, neutral or invalid cue appeared for 150 ms. The target then immediately appeared in the response button and participants had to click on the correct response button. If participants failed to respond with 2,000 ms a 'Time Out' message appeared on screen and the start button for the next trial appeared. If participants did not initiate mouse movements as soon as the target appeared away a message stated, 'Move your mouse as soon as the responses appear!'

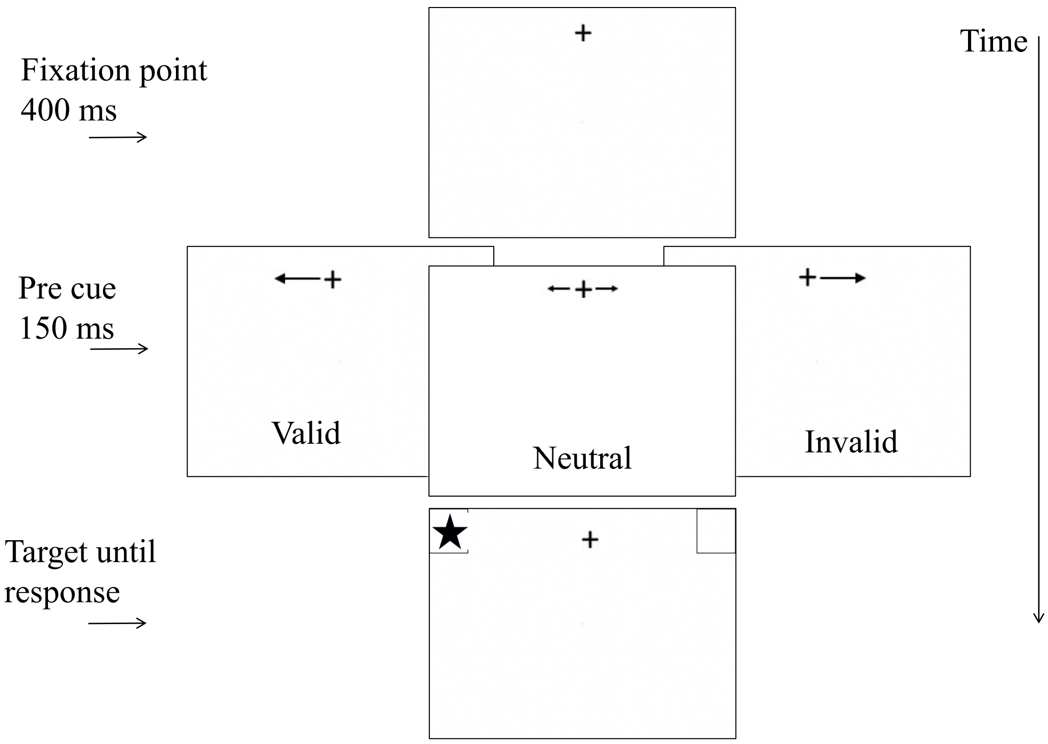


Figure 2.1. Sequence of events in the mouse tracking Posner trial. Participants are asked to select the target (a solid black star) which appeared on the left or the right. Central cues consisted of a black arrow which were either valid, neutral or invalid.

In the valid condition, before each target a single arrow pointed to the black box where the target would appear, which was the same location as the correct response box. In the invalid condition, a single arrow would point to the opposite box the target would appear in, which was in the different location to the correct response box. When a cue indicated a direction, the target would be present on that side in 80% of trials (valid condition) and on the opposite side in 20% of trials (invalid condition). In the Neutral condition, two arrows pointed in different directions to both possible locations/response boxes; the target would appear on either side with equal probability. All trials were presented in a random order. Each participant took part in a total of 300 trials.

2.4 Results

Data preparation. The only trials which were removed were when participants RT's exceeded the 2,000 ms as no data was recorded (this occurred in 11 trials).

Response times and initiation times. The standard Posner task uses RT's to measure task efficiency. The RT's, as reported in Table 2.1, demonstrate that RT's were fastest in the Valid Condition and longest in the Invalid Condition. Neutral cues were neither faster than valid cues or slower than invalid cues which is to be expected from a control condition. The differences between the groups were statistically significant as determined by a one-way ANOVA $F(2, 30) = 10.71, p < 0.01; \eta2 = 0.42$. Pairwise comparisons of the means using Tukey's Honestly Significant Difference procedure indicated that there were significant comparisons between Valid cues and Neutral cue, $p < 0.05$; Valid and Invalid cues, $p < 0.01$; but no significant differences between Neutral and Invalid Cues, $p > 0.05$.

Given the simplicity of the task it should be expected that participants were able respond quickly in each condition. As shown in Table 2,1, the initiation times were lowest in the valid condition and highest in the neutral condition However, there was no statistically significant differences between groups as determined by a one-way ANOVA $F(2, 30) = 3.08$, $p > 0.05$; $\eta2 = 0.18$.

Table 2.1. Initiation Times, Response Times, Maximum Deviation and Area Under the Curve for Each Cue Type: Valid, Neutral and Invalid.

Cues	Response time (ms)	Initiation time (ms)	Maximum deviation	Area under the curve
Valid	607	60	0.06	0.07
Neutral	793	86	0.23	0.33
Invalid	852	70	0.74	1.47

Response trajectories. As shown in Figure 2.2, when plotting the overall average response trajectory of each participant, the most direct responses occurred when valid cues were present, whilst the curvature of the trajectory increased for neutral cues the curvature of the trajectory is the largest when invalid cues are used. In Figure 2.3 where each individual trajectory has been plotted for all trials, the valid, neutral and invalid condition demonstrate that the most direct responses occur with valid cues whilst curvature is largest when invalid cues were used. Due to the different ways the averages have been calculated the average line in Figure 2.2 (an average calculated from the average of each participant) differs slightly from the average line in Figure 2.3 (averaging across all trials ignoring participants). is also reflected in Figure 2.3, where each individual trajectory has been plotted for all trials in the valid, neutral and invalid condition. These figures also clearly demonstrate increased activity in the upper left-hand quadrant near the alternative response button as the cues progress from valid, to neutral to invalid.

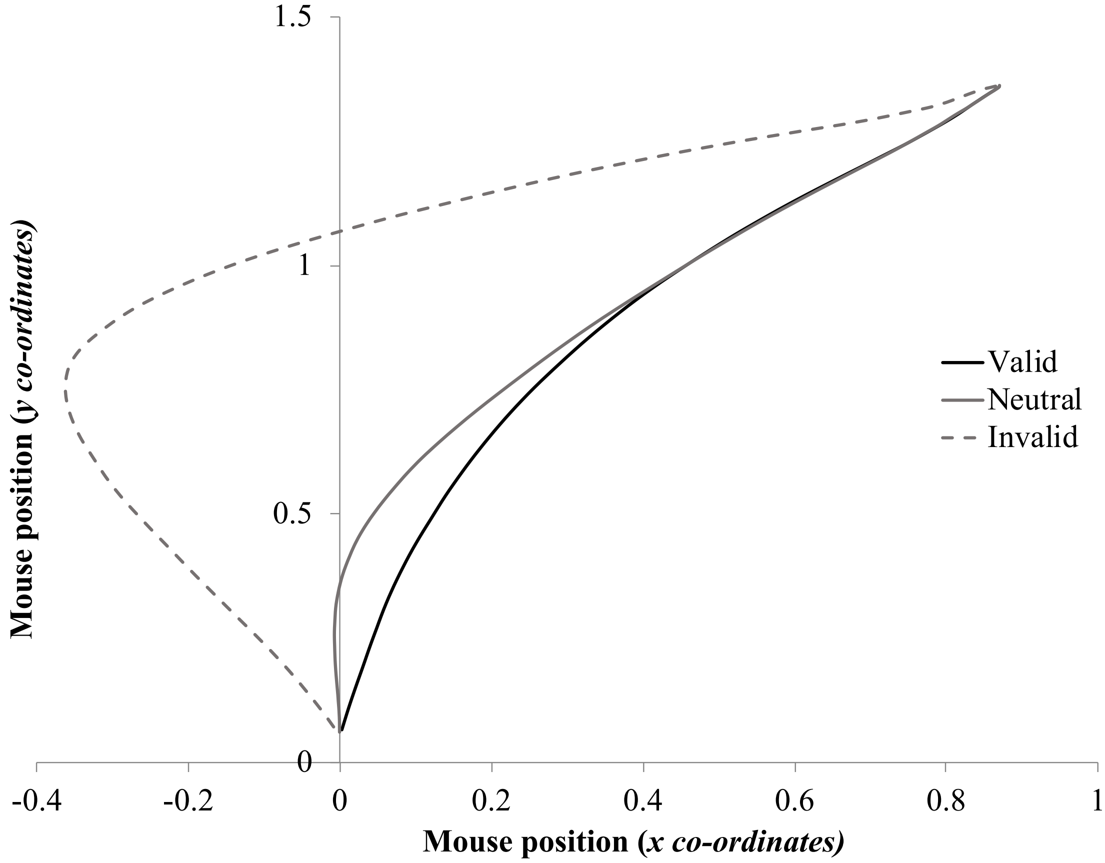
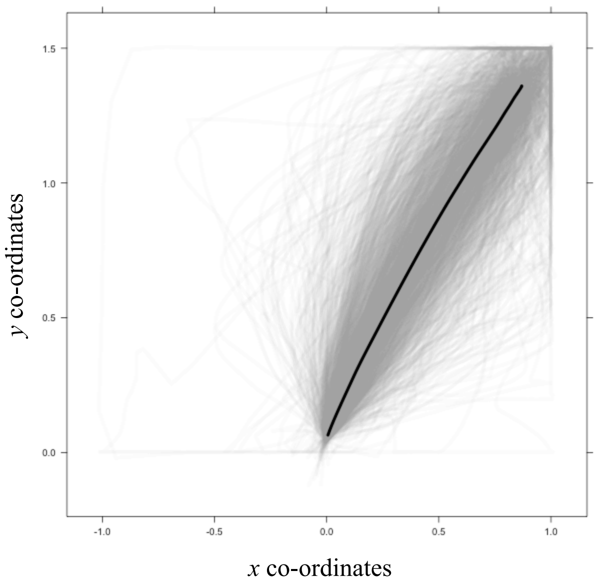
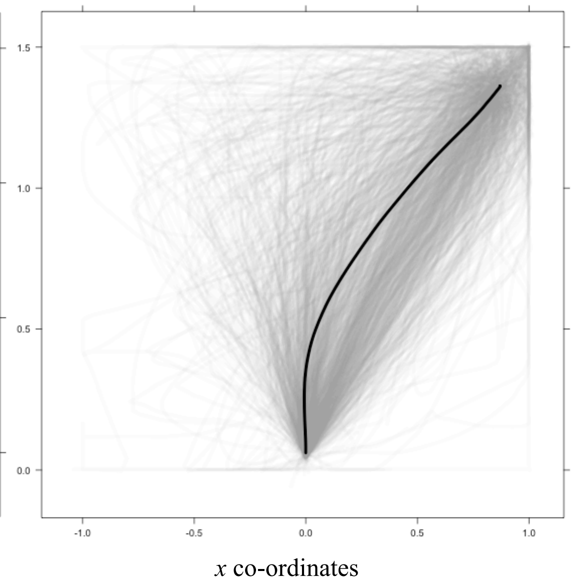


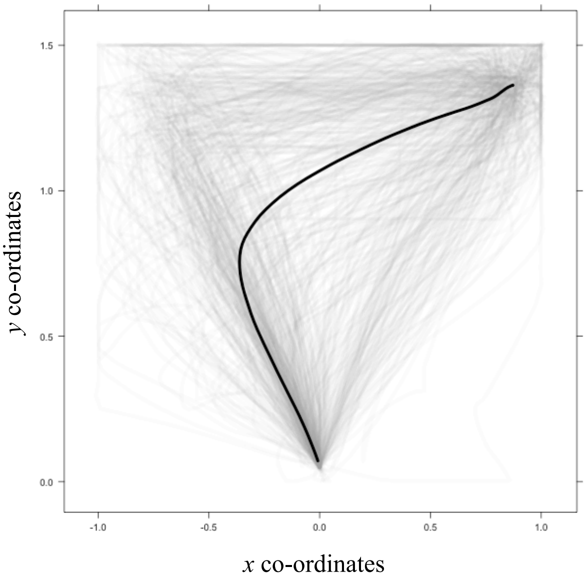
Figure 2.2. The average response trajectory of each participant when a Valid cue, Neutral Cue and Invalid Cue were presented with a target.



(a) Valid cue



(b) Neutral cue



(c) Invalid cue

Figure 2.3: All response trajectories for a trial, each line represents a response trajectory from the ‘Start’ button to response button for: (a) Valid cues, (b) Neutral cues and (c) Invalid Cues.

Maximum deviation. The maximum deviation measurement, as reported in Table 2.1, also demonstrates that maximum deviation was lowest in the Valid Condition and highest in the Invalid Condition. Neutral cues were neither higher than valid cues or lower than invalid cues which is to be expected from a control condition. The differences between the groups were statistically significant as determined by a one-way ANOVA $F(2, 30) = 35.78$, $p < 0.01$; $\eta 2 = 0.71$. Pairwise comparisons of the means using Tukey’s Honestly Significant

Difference procedure indicated that there were significant comparisons between Valid and Invalid cues, $p < 0.01$; Neutral cue and Invalid cues, $p < 0.01$ but no significant differences between between Valid cues and Neutral cue, $p > 0.05$.

Area under the curve. The area under the curve measurement, as reported in Table 2.1, demonstrate that area under the curve was lowest in the Valid Condition and highest in the Invalid Condition. Neutral cues were neither higher than valid cues or lower than invalid cues which is to be expected from a control condition. The differences between the groups were statistically significant as determined by a one-way ANOVA $F(2, 30) = 31.90$, $p < 0.01$; $\eta 2 = 0.68$. Pairwise comparisons of the means using Tukey's Honestly Significant Difference procedure indicated that there were significant comparisons between Valid and Invalid cues, $p < 0.01$; Neutral cue and Invalid cues, $p < 0.01$ but no significant differences between between Valid cues and Neutral cue, $p > 0.05$.

Distributions. It is possible that in some trials participants moved directly towards the correct response whereas in other trials participants moved towards the incorrect alternative and by averaging across both types of trajectories this resulted in an overall curved response. In order to address this issue Freeman and Ambady (2009) suggest reviewing the distributions of the response trajectories. If trajectories moved straight towards the response it is expected the maximum deviation would be small whereas if there was movement towards the alternative response maximum deviation would be large. By investigating any potential bimodality in the data, it is possible to see if the response trajectories included both responses. It is important to note that the bimodality reported in this section of each chapter is present for each participant and all analysis has been completed on the means of each participants which is normally distributed.

In terms of initiation time, Figure 2.4 demonstrates that initiation times for valid and invalid cues occurred in the first 50 ms whereas initiation times in the neutral cue occurred in the first 100 ms with a second peak appearing in the right tail. In order to assess bimodality, Hartigans' dip test (Hartigan and Hartigan, 1985) was used. This statistic is calculated as the maximum difference between the observed data provided and a unimodal distribution which is plotted to minimise these differences. If the difference between these two distributions is at or greater than 95th percentile then the distribution is deemed to be bimodal. Hartigans' dip test confirmed there was no bimodality for the valid condition; $D = 0.01$, $p > 0.05$ and the invalid condition; $D = 0.02$, $p > 0.05$. However, for the neutral condition, bimodality was evident; $D = 0.05$, $p < 0.05$. This demonstrates that whilst with valid and invalid cues participants were able to facilitate faster movement to the response buttons, with neutral cues participants sometimes hesitated in initial movements. Whilst initiation times were not significantly different in each condition, Table 2.1 demonstrates they were higher in the neutral condition. It is also worth noting that the long right tail distributions from the valid cue and invalid cue suggest that exclusions after 100 ms may have been beneficial to this analysis.

The density plots in Figure 2.4 demonstrate that the distribution for maximum deviation in the valid condition is not bimodal, but two small peaks appear in the distribution for the neutral condition. However, Hartigans' dip test demonstrated there was no bimodality in the valid condition $D = 0.02$, $p < 0.05$, or in the neutral condition, $D = 0.02$, $p < 0.05$. But as evidenced in the response trajectories plots in Figure 2.2 and Figure 2.3, in the invalid condition participants reach towards the alternative response before choosing the correct response. This is also demonstrated in the distribution of maximum deviation whereby bimodality was confirmed by Hartigans' dip test for unimodality/multimodality, $D = 0.08$, $p < 0.01$.

As shown in Figure 2.4, the distributions for area under the curve in the valid and neutral condition are not bimodal. This was confirmed by Hartigans' dip test for unimodality/multimodality in the valid condition, $D = 0.01$, $p > 0.05$; and the neutral condition, ($D = 0.02$, $p > 0.05$). However, as shown in the previous trajectory plots (Figure 2.2 and Figure 2.3) and the maximum deviation distributions it appears in the invalid condition participants reached towards the alternative response before correcting their response trajectories. This bimodality was confirmed by Hartigans' dip test for unimodality/multimodality, $D = 0.09$ $p < 0.01$.

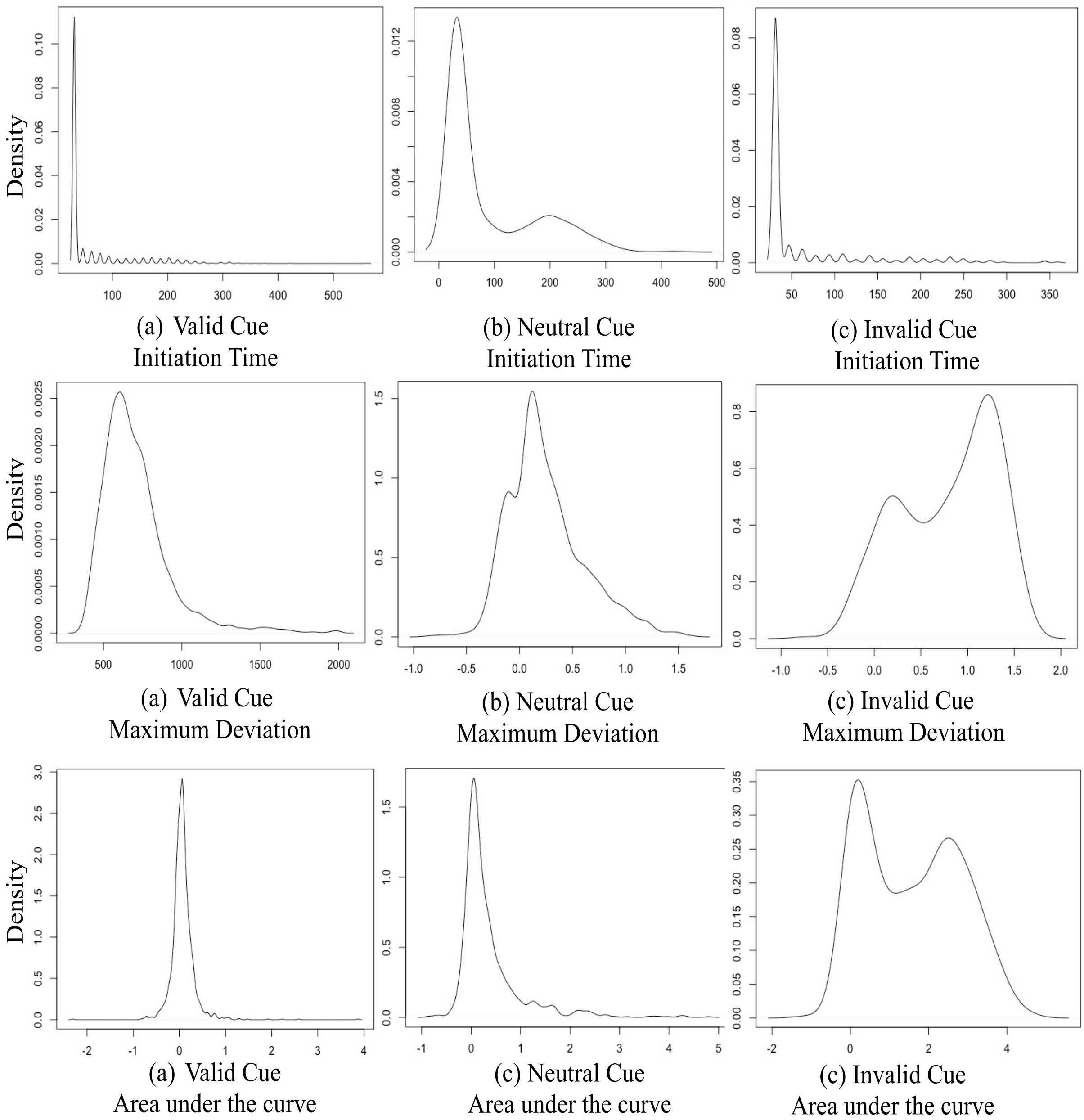


Figure 2.4. Distributions across conditions (a) Valid cues, (b) Neutral cues and (c) Invalid cues for initiation times, response times, maximum deviation and area under the curve. Due to the different densities in each condition the scale on the y-axis vary.

2.5 Discussion

Overall, the results from the present experiment demonstrate that participants perform better at locating a target when valid cues are used, and the use of invalid cues comes at a cost.

The typical measurement used in Spatial Orientating paradigms are RT's, the RT's in Experiment 1, replicate previous findings (Posner, 1980) that participants are significantly faster at discriminating the location of a target when the cues are valid compared to when they are invalid. Whilst the neutral cues were not significantly different from invalid cues, response time performance was, as expected, between both valid and invalid trials. Based on the RT's alone, it could be assumed that participants performance in neutral cues was similar to those in invalid cues. However, the subsequent analyses on response trajectories suggest a different conclusion.

In terms of initiation times, although initiation times were higher in the neutral condition, as expected there were no significant differences between conditions. This suggests that participants were able to initiate responses as soon as possible. However, the distributions of initiation times (Figure 2.4) demonstrated that there was significant bimodality in the neutral condition. This suggest with these non-directional cues rather than moving directly to the response button without stopping participants were hesitating and initiating a second cluster of movement around 200 ms. This may also explain why RT's were longer in the neutral condition and performance was similar to those of invalid cues.

The curvature of the average response trajectories and trial by trial plots of response trajectories (Figure 2.2 and Figure 2.3) not only demonstrate that participants mouse movement was more direct in the valid cue condition compared to the invalid cue condition, they also demonstrate that participants attention was directed to the alternative option before movement was corrected. Unlike RT's, it would appear that participants performance was more similar to those from the valid cue condition. These findings were also supported by corresponding maximum deviation and area under the curve measurements which showed there were higher values in the valid condition compared to the invalid and neutral condition performance was similar to valid cue performance. The distributions of the maximum deviation and area under the curve validate the previous findings that performance is hindered in the invalid condition because attention is initially directed to the alternative option; significant bimodality is found in both distributions of the maximum deviation and area under the curve.

It would therefore appear that the use of a central arrow can symbolically orientate attention endogenously to the incorrect answer. It is worth noting that whilst the majority of studies use an arrow, subsequent studies have questioned the use of an arrow as a cue (Bayliss, Pellegrino & Tipper, 2005). Due to the how commonplace arrows are in our environment it has been suggested that arrows cause attention to be involuntarily directed to the intended location exogenously (Chica et al, 2014).

To conclude the results from Experiment 1, replicate the previous findings from Posner (1980) that RT's are shorter when valid cues are used and demonstrate that a valid predictive symbolic cue can facilitate the discrimination of target location compared with neutral and invalid cues. Importantly, the use of mouse tracking and analysis of trajectories extends this finding to reveal that the difference in RT's also reflect that valid and invalid facilitate a faster movement to a response, but it's harder to initiate movement with a neutral cue. Therefore, Mouse tracking can provide a viable and useful alternative measurement for other low-level visual attention tasks and may be applied to other tasks such as discrimination in visual search tasks, which will be explored in the next chapter.

Chapter 3 Mouse tracking and visual processing with distractors

3.1 Chapter summary

This chapter describes an experiment designed to replicate the finding that when undertaking a target discrimination task, the task is more difficult when distractors are present compared to when the target appears in isolation. Task difficulty has been demonstrated in previous studies through the speed-accuracy trade off paradigm whereby increased response and error rates were deemed to reflect slower rates of information processing in tasks when distractors were present (Carassco & McElree, 2001). This study replicates this finding by using mouse tracking as an alternative methodology. In addition to the typical measurements of increased response times and increased error rates. Replicating the findings of Carassoc and McElree (2001) mouse tracking demonstrated that having distractors present compared to when the target was presented in isolation resulted in increased curvatures in response trajectories, a larger maximum deviation, and a larger area under the curve, providing further evidence for the usefulness of mouse tracking to studying early attention mechanisms.

3.2 Introduction

As detailed in the Chapter 1 introduction, visual search tasks have been used extensively to investigate the role of visual attention. Much of the research to date has investigated how increasing the demands of attention (by increasing the number of stimuli on display) or focusing attention (through the introduction of cues) affects participants abilities to detect or discriminate a target. This current experiment will focus on how increasing set size effects attention when set size is increased through the introduction of distractors in a target discrimination search task.

Previous visual search research has shown that people are slower and less accurate at locating a target when it is displayed amongst an array of similar stimuli. As detailed in the introduction two standard tasks are used for measuring attention in visual search. First, feature search tasks test how easily participants are able to find a target amongst distractors that have different features. Second, conjunction search tasks test how easily participants can find a target with two features amongst distractors that share one of these features. Feature search tasks yield faster response times (RTs) and lower rates of accuracy compared with conjunction search tasks (Treisman & Gelade, 1980; Treisman, Sykes, & Gelade, 1977).

When increasing the number of stimuli on display (set size) with the introduction of distractors, RTs are differentially affected in feature search task and conjunction search tasks (Carrasco, Giordano & McElree, 2006). In feature search tasks, increasing the set size has little effect on RTs (Treisman & Gelade, 1980; Treisman & Gormican, 1988; McElree & Carrasco, 1999) However, in conjunction search tasks where attentional demands are higher, as set size increases RT increase (Treisman & Gelade, 1980; Wolfe, 1994; McElree & Carrasco, 1999).

The serial/parallel dichotomy key to the Feature integration theory (FIT; Treisman & Gelade, 1980), discussed in Chapter 1, suggests in simple feature search tasks information is processed in parallel. However, when attentional demands increase through the use of conjunctive distractors or because the number of distractors increase visual attention occurs serially. Evidence for this parallel/serial dichotomy has mainly arisen from visual search experiments relying on single point measures to reflect participants efficiency at visual search tasks such as error rates and the time taken to make the decision (RT). The assumption is that different RT's reflect the different underlying processing speeds, the faster the RT the more efficient the search (McElree & Carrasco, 1999). Plotting RT as a function of set size has been interpreted to indicate search efficiency, evidence for parallel processing has mainly arisen from the understanding that if the target 'pops out' and attention is directed to the target immediately the slope is nearer zero, whereas complex searches involving serial processing will have steeper slopes with slopes greater than 25-30 ms/item (Wolfe, 2010). Although it is worth noting that the use of RT's in distinguishing between these two mechanisms has been questioned. For example, Townsend (1990) illustrated that whilst a shallow slope of 5 ms/item may be interpreted as processing occurring in parallel this could also technically occur because of serial processing whereby one item is processed every 5 ms. They conclude that at most, different RT slopes suggest differences in processing capacity. Wolfe (1998) also points out that when viewed altogether the evidence from visual search tasks does not show a dichotomous division but a continuum of search behaviours.

The assumption that differences in RT's solely arise from differences in processing speeds and mechanisms has also been questioned. A decision may be made earlier due to other factors even if underlying processing speeds are the same (McElree & Carrasco, 1999). Decision criteria such as increasing complexity of the task (Sperling & Dosher, 1986) or sensory factors such as eccentricity (Carrasco, Evert, Chang, & Kantz, 1995) have been shown to affect discriminability/accuracy which play a key role in set size effects. Response times can also be influenced by possible speed/accuracy trade-offs whereby participants either give a faster performance resulting in higher level of errors or a slower performance resulting in less errors.

As RT varies with processing speed and/or discriminability, it is not always possible to use a paradigm which relies on RT to identify underlying processes in visual search tasks. Some visual search experiments have used short presentation times and the proportion of correct responses as a measure of performance. For example, Verghese and Nakayama (1994) manipulated a target vertical line amongst distractors which differed from the target in either orientation, colour (red to almost green) or spatial frequency (5° - 90°difference). Participants had to identify whether the target was present or absent (there was a 50% chance it would be present). They measured the probability to correctly detect a target (80 % discriminability) as a function of the duration of the display (which differed from 30 to 360 ms in increments of 30 ms) and the stimulus difference of targets and distractors. They found the effect of increasing set size was different for each attribute. Colour resulted in small set-size effects, orientation discrimination showed a large set size effect and spatial frequency had an intermediate effect.

To isolate how set size affects processing speeds in target discrimination other researchers have used a response-signal Speed–accuracy Trade-off (SAT) paradigm as described in the Chapter 1 (McElree & Dosher, 1989; Wickelgren, 1977). By providing time course data that measures both speed and accuracy it controls for the speed accuracy trade-off and provides a stronger basis of analysis to investigate visual search tasks (McElree & Carrasco, 1999). McElree and Carrasco (1999) used both RT analysis and SAT to investigate the differences in set size effects associated with feature and conjunction search tasks. In the RT experiment, participants had to identify whether a blue vertical target was present amongst blue tilted distractors (feature search task) or blue tilted and red vertical distractors (conjunction search task). The researchers manipulated both the set size (4, 7, 10, 13, or 16 elements) and viewing time which was either fixed at 150 ms or participants were given free viewing and the stimuli was displayed until the participant responded. Detection speed (RT's) and discrimination (accuracy) were recorded. Similar to previous findings, evidence of set size affecting accuracy were more apparent in the conjunction search task than feature search tasks for both fixed and free viewing conditions.

In the second SAT experiment, participants had to identify whether the target was present or absent in both feature and conjunction search tasks. Participants were limited to respond when a tone was played after one of seven randomly chosen durations from 210, 300, 450, 600, 750, 900, or 2,000 ms after the stimuli was initially presented. As using a SAT procedure involves substantially more trials therefore only three set sizes were used (4, 10 and 16). Participant's also had to take part in practise trials to become used to responding on cue and were trained to respond within 300 ms of the tone. By plotting a SAT function curve for both feature and conjunction search tasks (Figure 3.1) the authors were able to analyse differences in the rate, intercept and asymptote of each line of best fit to demonstrate differences in processing. They found in both conditions the asymptotic performance/discriminability decreased as set size increased consistent with claims that increasing elements increases noise in the process (Sperling & Dosher, 1986). However, set size had no effect on intercept or rate (processing speed) in the feature search task but decreased with larger set sizes in the conjunction search task. In summary, by using a SAT procedure the authors were able to separate discriminability from processing speed and found set size affected accuracy in both searches but only detection speed was affected in conjunction search tasks. Relating their findings to the dichotomy presented in FIT (Treisman & Gelade, 1980) the authors suggested that because fits of models to the data based on serial processing could not account for the small magnitude of differences between the two conditions, both feature and conjunction searches occurred in parallel.

To address the role of covert attention on processing speed in visual search tasks Carrasco and McElree (2001) also used a response-signal SAT procedure (Figure 3.2). In a target discrimination task, participants were asked to identify whether a target was tilted to the right or left. In both feature and conjunction search tasks a total of three variables were manipulated. First the set size, in the feature search task the target was presented in isolation or with three or seven vertical distractors. In the conjunction search task, the target was presented in isolation or with three or seven distractors which differed in spatial frequency or orientation. Second the type of cue used, before the onset of the target covert attention was directed to the target, in half of the trials a peripheral, transient pre cue of a small circle appeared next to the proposed target location; in the other half a neutral central circle. Finally, in all conditions, participants were limited to respond to a response tone which occurred 40, 94, 200, 350, 600, 1000 and 2000 ms after the onset of the target display.

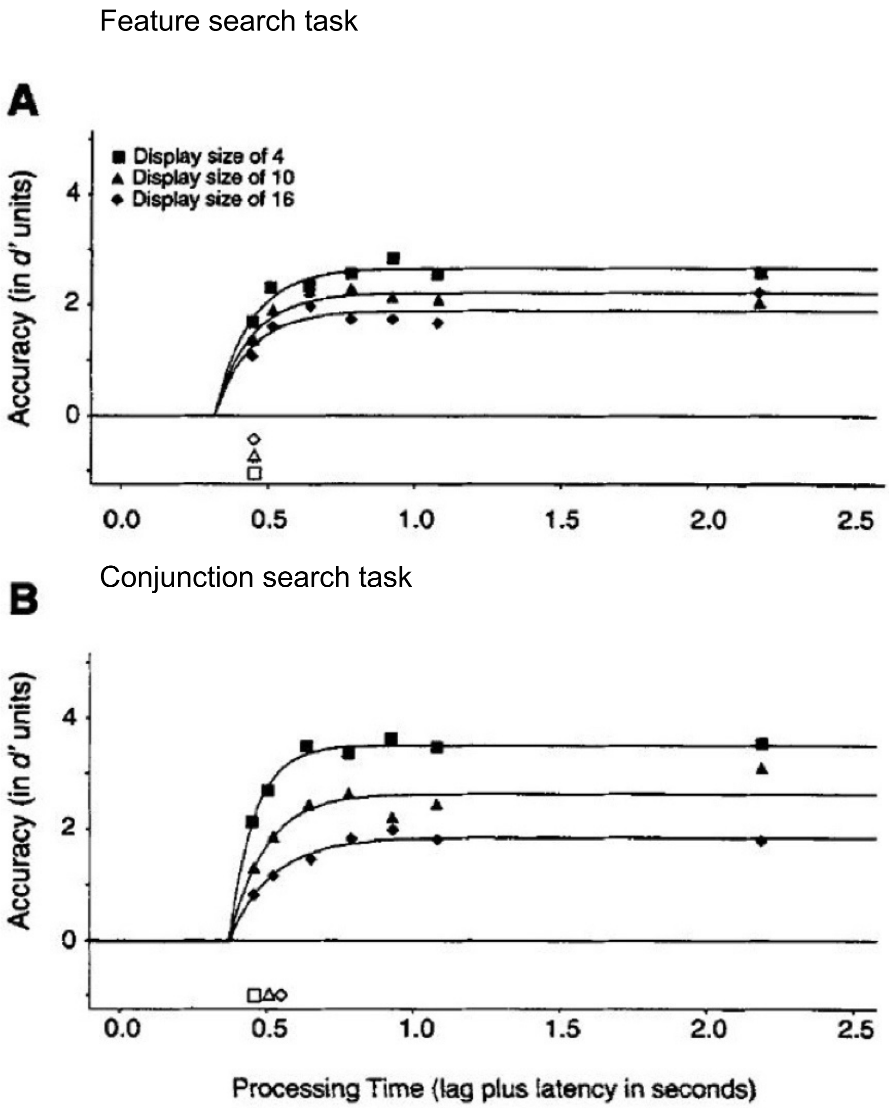


Figure 3.1. SAT function curves in which accuracy is plotted as function of processing time for different set sizes in both feature and conjunction search tasks. The open symbols below chance level demonstrate the moment the corresponding functions reach two thirds of the asymptote and illustrate the curves display proportional dynamics and thus have comparable underlying retrieval speeds. Taken from McElree, B., & Carrasco, M. (1999). The temporal dynamics of visual search: evidence for parallel processing in feature and conjunction searches. *Journal of Experimental Psychology: Human Perception and Performance, 25*, 1527.

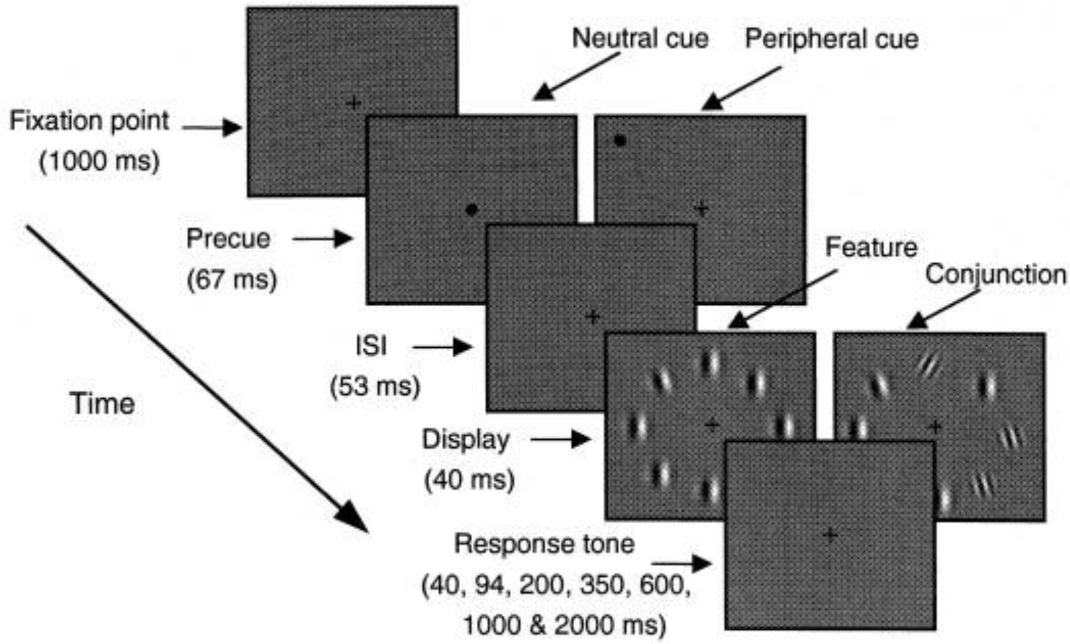


Figure 3.2. Sequence of events used in the response-signal SAT procedure for features search and conjunction search tasks. Taken from Carrasco, M., and McElree, B. (2001). Covert attention accelerates the rate of visual information processing. *Proceedings of the National Academy of Sciences*, *98*(9), 5364.

For both feature and conjunction search tasks, a line of best fit based on 3 parameters (asymptote, intercept and rate) were fitted to the average data (Figure 3.3). These demonstrated that discriminability in both feature and conjunction search tasks, as measured by the levels of asymptotic accuracy, was improved when covert attention was manipulated by a peripheral cue compared to a neutral cue. Processing time as measured by intercept and rate, was unaffected by set size in the neutral feature search task but clearly affected by set size in the neutral conjunction search task. Thus, replicating the findings from McElree and Carrasco (1999). The authors concluded that there was evidence of parallel processing in both tasks, but processing is faster when covert attention is used in tasks where is attention is already focused (smaller set size) and not allocated across a larger display. Increasing the number of distractors present in a task resulted in slower processing speeds for conjunction search tasks. However, increasing distractors did not result in slower processing speeds in the feature search task. This finding has subsequently been disputed.

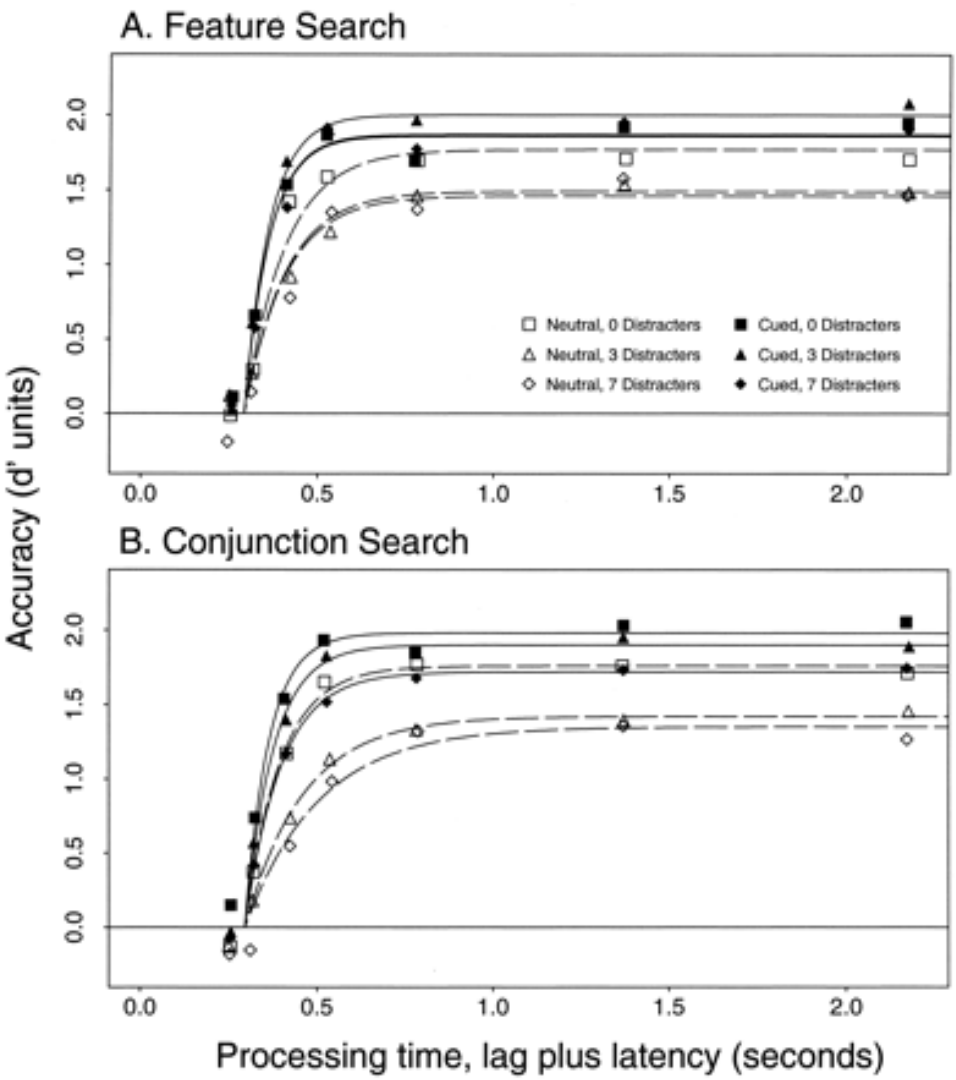


Figure 3.3. SAT function curves in which accuracy is plotted as function of processing time for different set sizes and cues in both feature and conjunction search tasks. Taken from Carrasco, M., and McElree, B. (2001). Covert attention accelerates the rate of visual information processing. *Proceedings of the National Academy of Sciences*, *98*(9), 5365.

Kent, Howard, and Gilchrist (2012) reanalysed the data in the feature search task when a central cue was present and found that including a different rate parameter for set size 1, resulted in a faster search rate than those in set sizes 4 and 8. Therefore suggesting that increasing distractors did result in slower processing speeds in feature search tasks. In order to experimentally test whether processing speeds were affected by introducing distractors Kent et al. (2012) replicated Carrasco and McElree (2001)'s visual search task using a SAT paradigm (Figure 3.4) but focused solely on a single feature orientation discrimination task with a neutral cue. Participants had to discriminate whether a Gabor patch was tilting to the left or right of the screen. Set sizes were manipulated in four distractor conditions which included either 0, 1, 2 or 3 distractors. Duration of stimuli (40 ms or 140 ms) was also manipulated. Whilst no differences were found in discriminability (asymptotes) across different set sizes or duration differences it was noted that participants already performed the task close to ceiling levels. It was found that visual information processing was faster when no distractors were present compared with set sizes with 1, 2 and 3 distractors. The authors concluded this was due to attentional resources being split as set sizes increased. Stimulus duration had no effect on processing speeds when a target appeared in isolation but did impact processing speeds when it appeared with distractors. The authors suggested that this may be because when one item is present any information accumulated will increase evidence for the correct response. However, when distractors are present, information is accumulated from distractors, so more time is needed to ensure the information is relevant and a correct response is made.

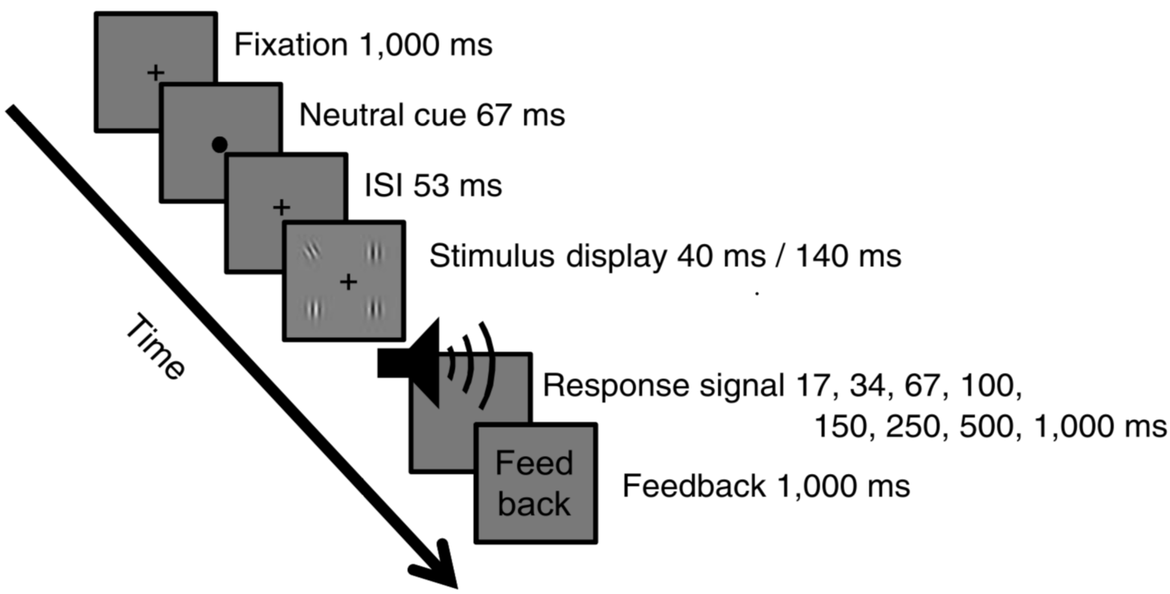


Figure 3.4. Sequence of events used in the response-signal SAT procedure for features search tasks. Taken from Kent, C., Howard, C. J., & Gilchrist, I. D. (2012). Distractors slow information accumulation in simple feature search. *Journal of vision*, *12*(1), 6.

As discussed in the introduction, there are many drawbacks associated with the SAT paradigm, but mouse tracking may offer a simple low-cost alternative to investigate set size effects in target discrimination tasks. Movement trajectories have been used previously in odd-coloured single feature visual search tasks. For example, in reaching movements Song and Nakayama (2006) demonstrated that when identifying a red coloured target from a display of green coloured distractors, (a single feature based search), as the number of distractors increased there were actually shorter trajectories with decreased curvature and concluded that increasing the number of distractors allowed for more efficient perceptual grouping. Song and Nakayama (2008) also used colour-oddity search tasks and presented participants with either one target and two distractors or a single target without distractors, these were randomly intermixed. Participants were asked to reach for and touch a lone or odd-coloured target as quickly as possible. To ensure there was ongoing competition between the target and distractors the colour of the target changed from red to green in each trial. Hand movements in single trials were direct with little variation between them. But by introducing distractors, trajectories became larger as the hand initially moved towards a distractor before moving towards the target. However, in terms of efficiency, accuracy and total time were not affected as the extra time spent reaching for a distractor was offset by shorter initial movements. The authors concluded that a new target is selected before initial movement starts.

The main aim of Experiment 3 is to investigate the impact of including distractors in a visual search task. Unlike Kent et al. (2012) who replicated Carrasco and McElree's (2001) neutral feature search task this experiment will use mouse tracking to replicate Carrasco and McElree's (2001) neutral conjunction task. In Carrasco and McElree's (2001) neutral conjunction task, participants were asked to identify which way a 2-cpd (cycle per degree) Gabor was tilting. Participants were presented with a pre cue of a neutral circle in the centre of the screen which did not indicate where the target was located. Participants were asked to respond 40, 94, 200, 350, 600, 1000 and 2000 ms after the onset of the target display. Set size was manipulated from 1 target and no distractors, 1 target and 3 distractors or 1 target and 7 distractors. The target was a conjunction of two features, spatial frequency (2-cpd versus 8-cpd) and orientation (30° tilt versus vertical). The data from Carrasco and McElree's (2001) conjunction search task and Kent, Howard, and Gilchrist's (2012) feature search task demonstrated that participants are better at discriminating which way a target is tilting when distractors are not present. As such we would expect the presence of distractors not only to result in longer RT's and higher error rates but also in indirect trajectories with increased curvature and the corresponding AUC and MD to be larger than when the target is presented in isolation.

3.3 Methods

Participants. Eleven members of the public (6 female) aged between 20 and 38 took part in the experiment, completing two blocks of the experiment. All participants had normal or corrected-to normal vision.

Materials and stimuli. Stimuli were displayed on a 15.4inch laptop screen with resolution of 1,280 x 800 pixel and 60 Hz maximum refresh rate. The stimuli were presented in a darkened room. Participants sat approximately 50 cm from the screen and moved a cordless mouse placed on the right-hand side of the laptop to respond.

Each stimulus consisted of Gabor patches (suprathreshold sinusoidal gratings vignette by a Gaussian envelope). The target was a 2 cycle per degree (cpd) Gabor patch that was tilted to the right or left. Distractors varied on two dimensions, either orientation (a vertical 2 cpd Gabor patch) or spatial frequency (an 8 cpd Gabor patch tilted to the same orientation as the target). For each trial, stimuli were presented in a grid format at a location equidistance from the centre of the screen (co-ordinates 320 px, 200 px; co-ordinates 320 px, 600 px; co-ordinates 960 px, 600 px and co-ordinates 960 px, 200 px)

The MouseTracker space represents a 2 x 1.5 rectangle, the start button and start of all response trajectories was located in the bottom centre of the screen (co-ordinates 640 px, 0 px). One response button (160 px wide x 256 px high) was located at the top left-hand side of the screen (co-ordinates 0 px, 800 px) and the other response button was located at the top right-hand side of the screen (co-ordinates 1024 px, 800 px).

Design and Procedure. The participants were told to identify whether a target was tilting to the left or right, see Figure 3.5 for sequence of events. The participants were familiarised with the target before the experiment started. In the first condition, the target was presented in isolation, hereafter referred to as the simple condition. In the second condition, the target was presented with three distractors, which as described above, varied on two dimensions: spatial frequency and orientation.

As shown in Figure 3.5, similar timings to Carrasco and McElree (2001) were used, the cue was presented for 67 ms in both experiments. However, due to difference in refresh rates it was not possible to match them exactly. The interval between the cue onset and the target onset was 117 ms whereas they used 120 ms. The timing between the cue onset and stimulus offset was also brief at 167 ms (versus 160 ms).

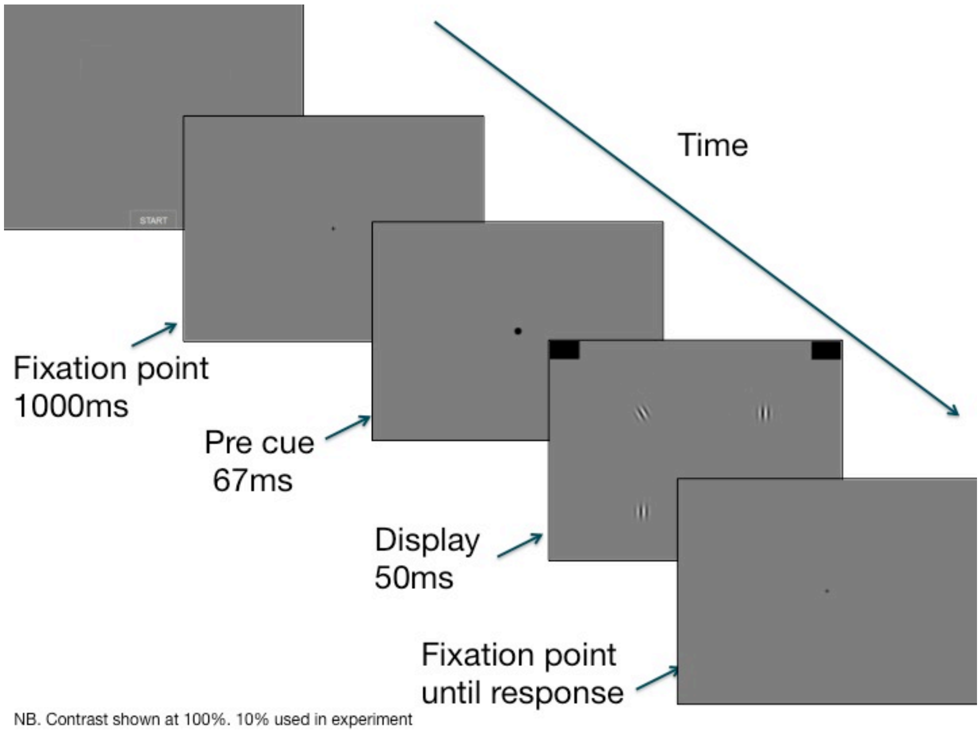


Figure 3.5. Sequence of events in a distractor trial. Participants are asked to make a two alternative forced choice on whether a target (a tilted Gabor patch) is orientated to the left or right. The target is this example is displayed with distractors.

Participant's initiated each trial by clicking the Start button in the bottom centre of the screen. They were told to move their mouse as soon as they saw the Gabor patches. If they believed the target tilted left, they clicked the top left-hand black button. If they believed the target tilted to the right, they clicked the top right-hand button. Participants were given feedback (a large red cross) if the answer given was wrong. If participants failed to respond within 3,000 ms a 'Time Out' message appeared on screen and the start button for the next trial appeared. If participants did not initiate mouse movements as soon as the target appeared away a message stated, 'Move your mouse as soon as the responses appear!'

The target was presented 720 times in total, 360 times with the distractors and 360 in isolation. Trials were presented in a randomised order. Whether the target was left, or right tilting was also counterbalanced.

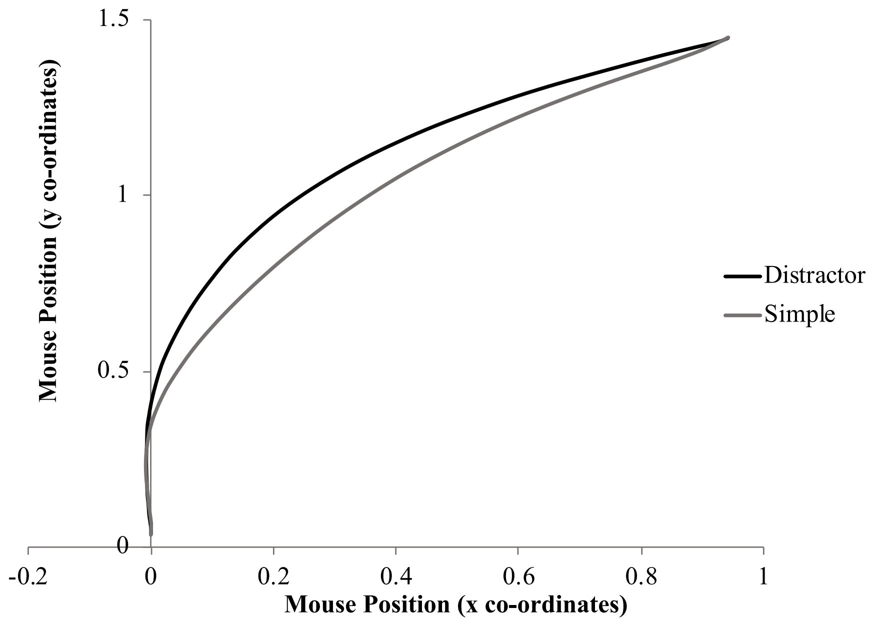
3.4 Results

Error rates. One participant was excluded as 56% of trials were not completed, post experimental discussion revealed this person had not been clicking a response until halfway through the experiment. Once removed, a paired samples t-test revealed that the mean percentage of errors made for the simple condition (ss = 1) (M = 2.00, SD = 1.93) was significantly different from the distractor condition (M = 5.27, SD = 1.93); 95% CI [0.61 to 5.93], $t(9) = 2.79, p < 0.05$). $d = 0.88$.

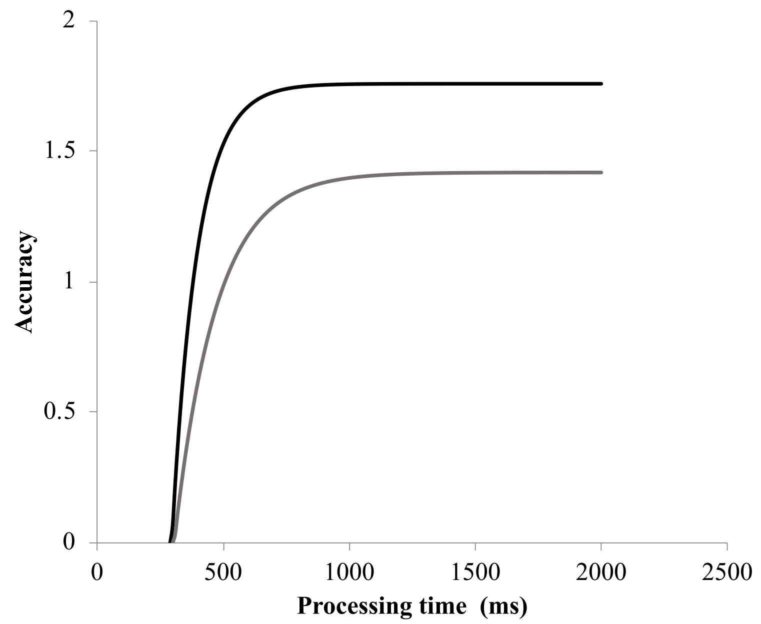
Exclusion criteria. Of the remaining participants, to ensure participants had responded quickly, trials initiated later than 500 ms, RT's longer than 2,000 ms as well as trials where participants failed to response and incorrect trials were also excluded. This resulted in 8% of trials being excluded from the distractor condition and 4% of trials being excluded from the simple condition.

Response and initiation times. The average response time was shorter in the simple condition when distractors were absent compared to the distractor condition where distractors were present. A paired samples t-test demonstrated that the RT's in the simple condition (M = 899, SD = 162) were significantly shorter than the distractor condition (M = 970, SD = 159); 95% CI [34.08 to 107.64], $t(9) = 4.36, p < 0.05$), with a large effect size d =1.38. In terms of initiation times, participants moved their mouse quickly in both conditions. A paired sampled t-test demonstrated that the average initiation time for the distractor condition (M = 157 ms, SD = 77) compared with the simple condition (M = 154 ms, SD = 77) was not significantly different; 95% CI [-6.49 to 1.70], $t(9) = -1.32, p > 0.05, d = 0.42$

Response trajectories. As shown in Figure 3.6, the average trajectory across each condition differs. The trajectory is more direct in the simple condition compared to the distractor condition. It also appears the shape of each trajectory follows a distinct pattern with participants moving the mouse towards the left-hand side of the screen before they make a decision. This is consistent with the different SAT curves found between the two conditions by Carrasco and McElree (2001) where differences in accuracy (intercept) and differences in processing time (rate) resulted in better performances in the neutral set size 1 condition. As shown in Figure 3.7, by plotting each trajectory made across all trials and all participants in each condition it is also possible to see that in the distractor condition, more participants moved towards the alternative option before eventually choosing the correct answer. The data was also analysed for the number of reversals made along the x-axis. A paired samples t-test revealed that whilst fewer x-flips were made in the simple condition (M = 8.3, SD = 1.38) compared to the distractor condition (M = 8.46, SD = 1.31) this was not significantly different; 95% CI [-0.03 to 0.32], $t(9) = 1.91$, $p > 0.05$), $d = 0.60$.



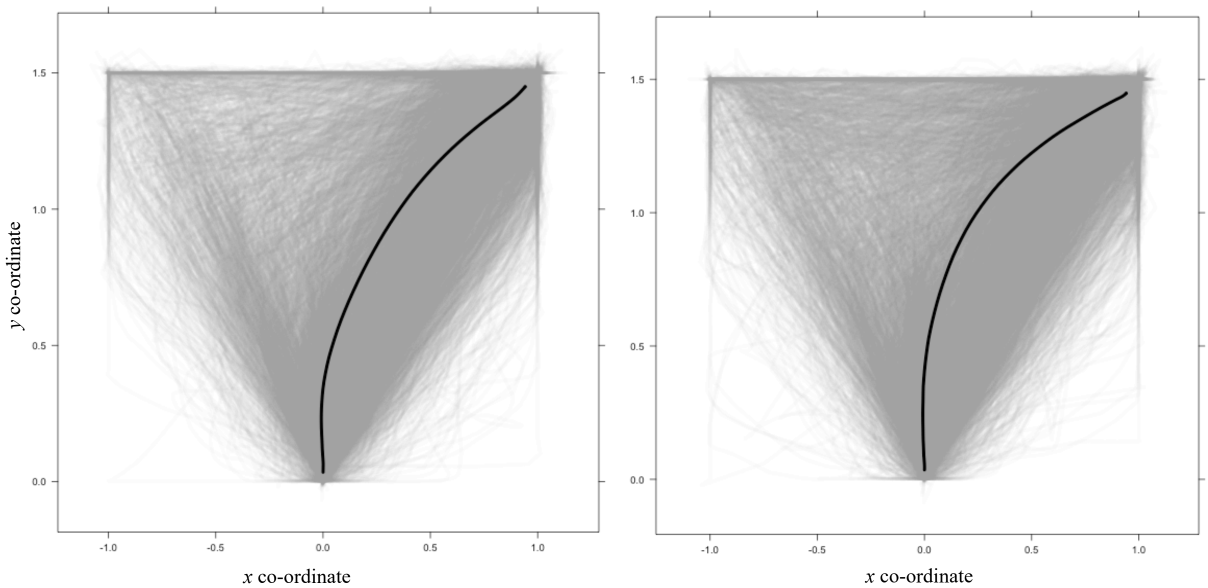
(a) Experiment 3 Mouse Tracking Data



(b) Recreated SAT Curves from McElree and Carrasco (2001)

Figure 3.6. A comparison of the findings of response trajectories from (a) Distractor and simple conditions from Experiment 3 and (b) SAT curves from Carrasco and McElree

(2001), recreated by using the equation described in the introduction $d(t) = \lambda\left(1 - e^{-\beta(t-\delta)}\right), for\ t > \ \delta, else\ 0,$ which plots differences in asymptote for the simple condition (λ = 1.76) and distractor condition (λ = 1.42), differences in rate between the simple condition (β = 0.0099) and the distractor condition (β = 0.0061) whilst take off parameters remain the same, δ = 296 ms.



(a) Simple condition **(b) Distractor condition**

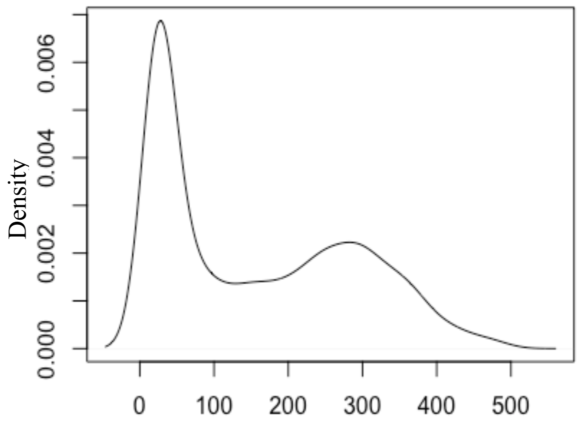
Figure 3.7. All response trajectories for a trial, each line represents a response trajectory from the ‘Start’ button to response button for: (a) Simple condition, and (b) Distractor condition.

Maximum deviation and Area under the curve. As expected from the response trajectories, the average maximum deviation was higher when distractors were present. A paired sample t-test demonstrated that differences between the simple condition (M = 0.37, SD = 0.17) and the distractor condition (M = 0.47, SD = 0.15) were significantly different: 95% CI [0.05 to 0.15], $t(9) = 4.45$, $p < 0.05$), $d = 1.41$. The average area under the curve was higher when distractors were present. A paired sample t-test demonstrated significantly differences between the simple condition (M = 0.71, SD = 0.40) and the distractor condition (M = 0.97, SD = 0.38); 95% CI [0.13 to 0.39], $t(9) = 4.48$, $p < 0.05$), $d = 1.42$. The effect size for both these analysis ($d = 1.41$ and $d = 1.42$) was found to exceed Cohen (1988)’s convention for a large effect ($d = 0.80$).

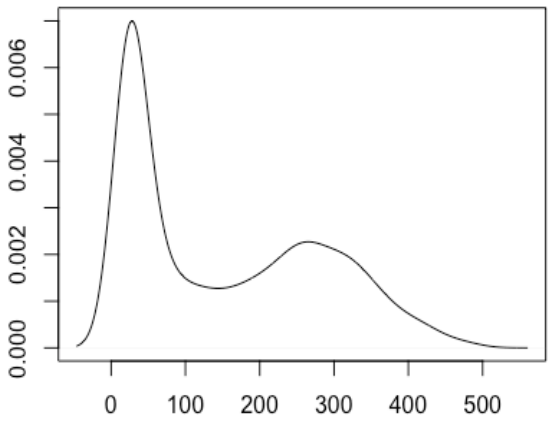
Distributions. As shown in Figure 3.8 (a and b), distributions for initiation times demonstrate participants responded quickly in both conditions with the majority of responses occurring within the first 100 ms and a second peak of responses occur around 300 ms. Bimodality across conditions was confirmed by Hartigans dip test; for the simple condition, D =0.06, $p <$ 0.01, and for the distractor condition D = 0.07, $p < 0.01$. Given this appears across both conditions it is unlikely to be driven by the conditions themselves. The bimodality also occurred across all participants and could simply reflect the design of the MouseTracker software which starts recording initiation times from a nudge or regrip of a mouse.

Distributions for maximum deviation, also did not differ between conditions (Figure 3.8 (b, and c)). For each condition there was potential bimodality as illustrated in a second peak forming at larger maximum deviations, this peak was larger for the distractor condition which suggests in more trial's participants were moving towards the alternative response. Also apparent in the simple condition is an additional peak forming on the left tail, this distribution could reflect that differences in hand kinematics. Movement in the hand towards the thumb side of the forearm (radial deviation of wrist) has more degrees of freedom than movement towards the little finger (ulnar deviation of the wrist; Holzbaur, Murray & Delp, 2005). When the correct answer is on the right-hand side these movements towards the left (negative MD) may become more frequent in faster responses. The Hartigans' dip test demonstrated that the distribution was bimodal in both conditions, for the simple condition $D = 0.10$, $p < .001$ and the distractor condition, $D = 0.08$, $p < .001$.

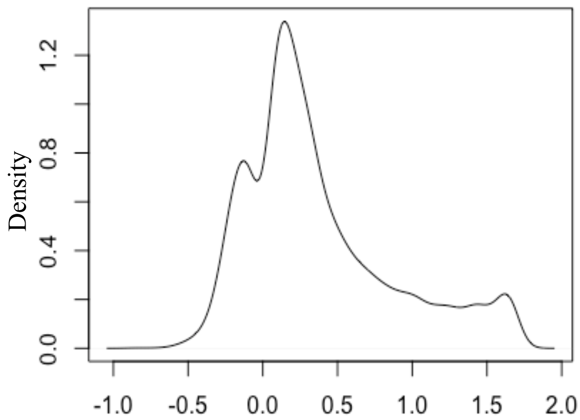
This bimodality is not evident in the distributions for area under the curve, as shown in Figure 3.8 (e, and f); distributions are similar in all conditions and peaks initially before distribution rises and dips in the right tail.



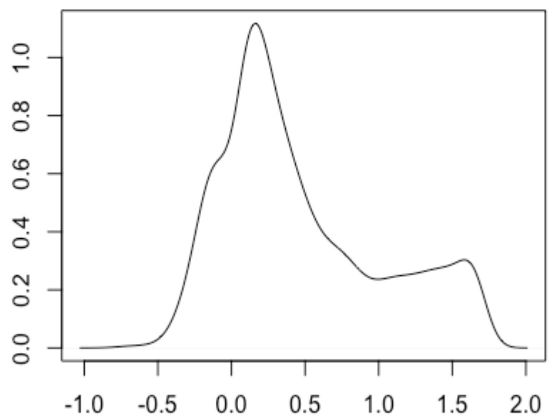
(a) Simple Condition Initiation Time



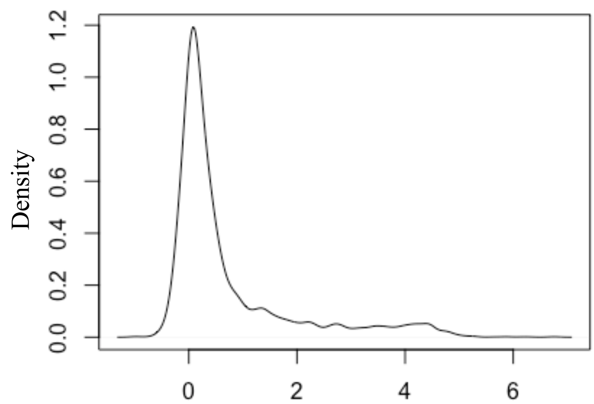
(b) Distractor Condition Initiation Time



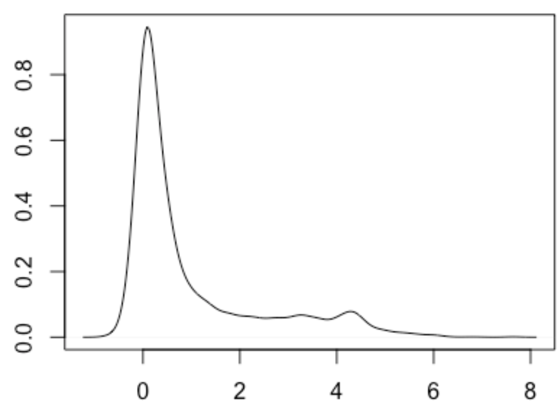
(c) Simple Condition Maximum Deviation



(d) Distractor Condition Maximum Deviation



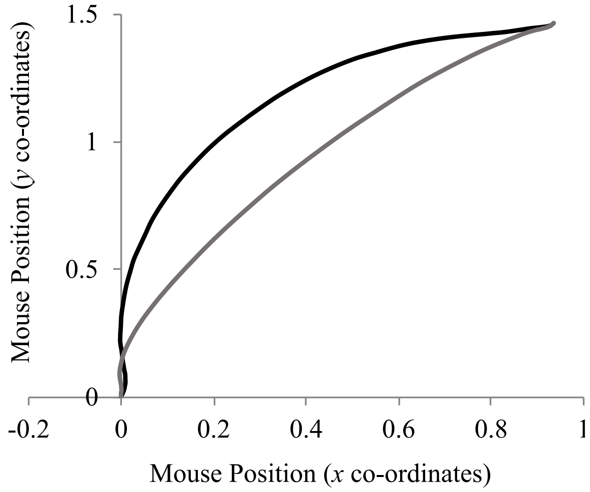
(e) Simple Condition Area under the curve



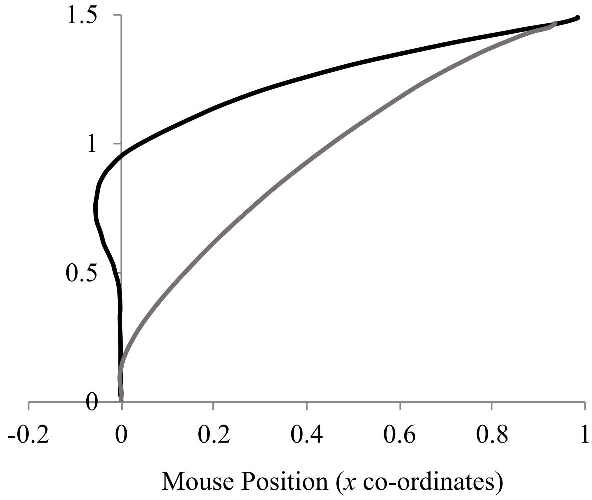
(f) Distractor Condition Area under the curve

Figure 3.8. Distributions across Simple and Distractor conditions for initiation times, maximum deviation and area under the curve.

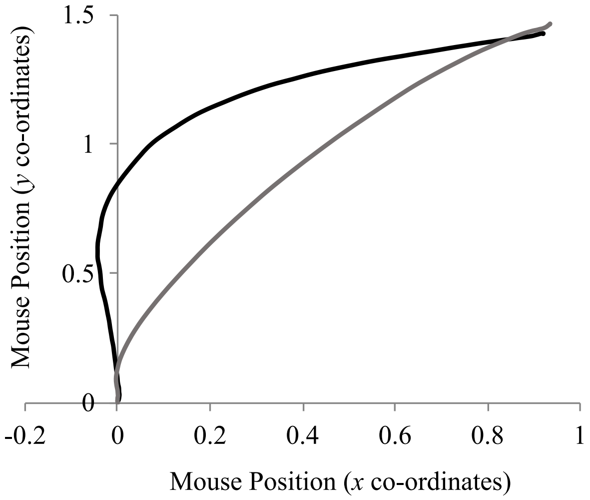
Individual differences. It is important to ensure the average trajectories displayed in Figure 3.6 are not a result of averaging across participants and to ensure response trajectory pattern was seen for most individuals who took part in the experiment. Figure 3.9 plots the trajectories for each individual in each condition. Whilst the shape of trajectories differed between each participant the same trend is clearly seen with the simple condition having a more direct trajectory (with the exception of Participant 8).



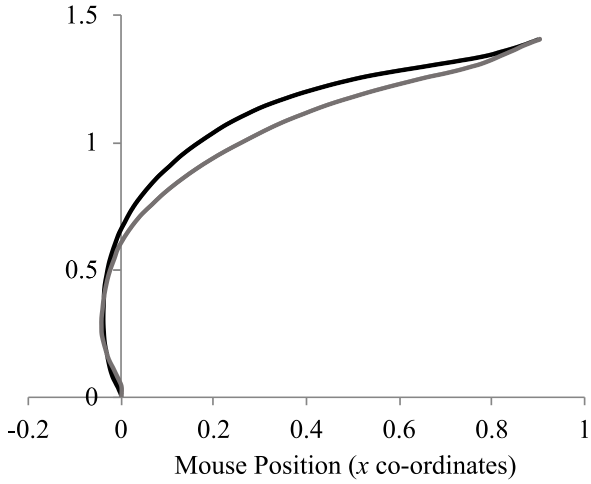
(a) Participant One



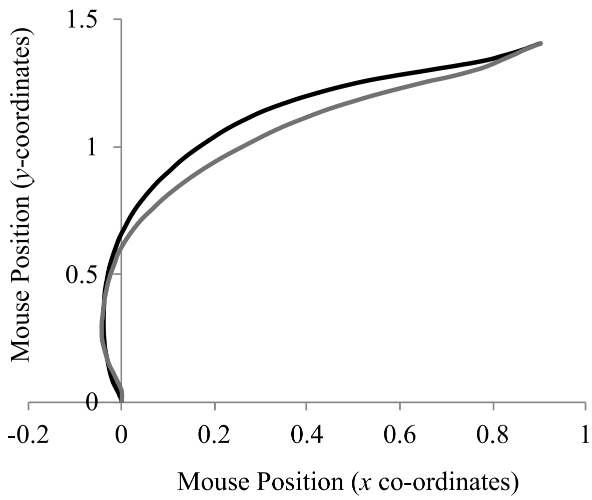
(b) Participant Two



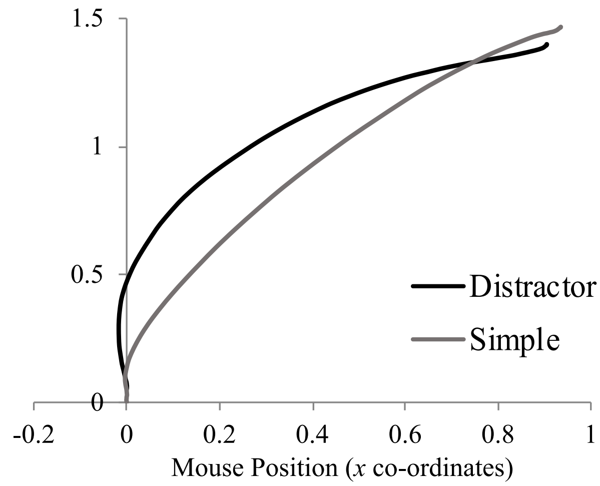
(c) Participant Three



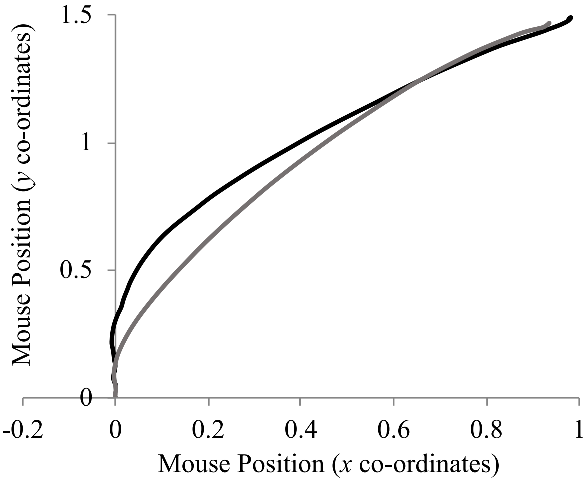
(d) Participant Four



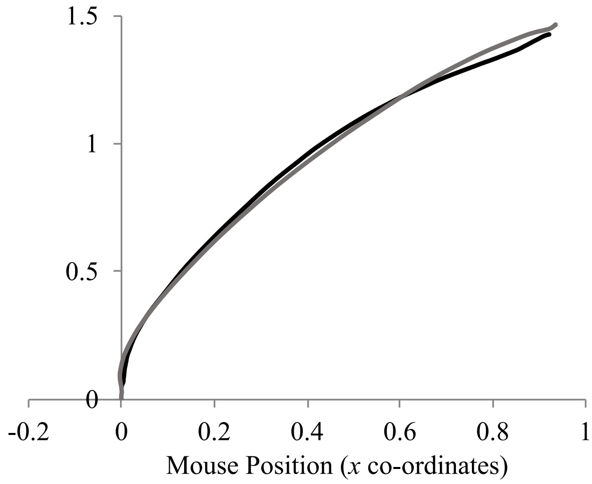
(e) Participant Five



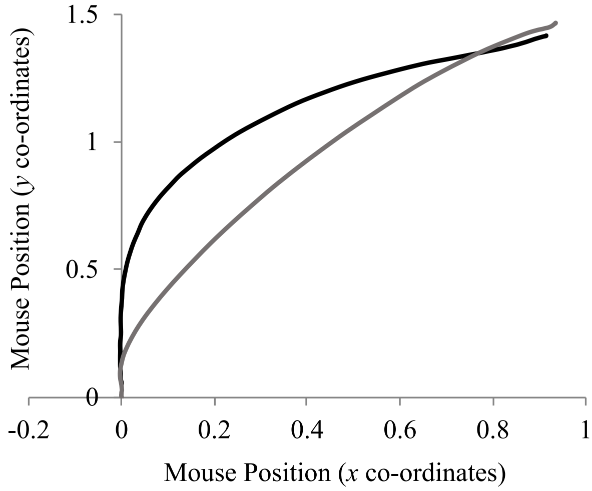
(f) Participant Six



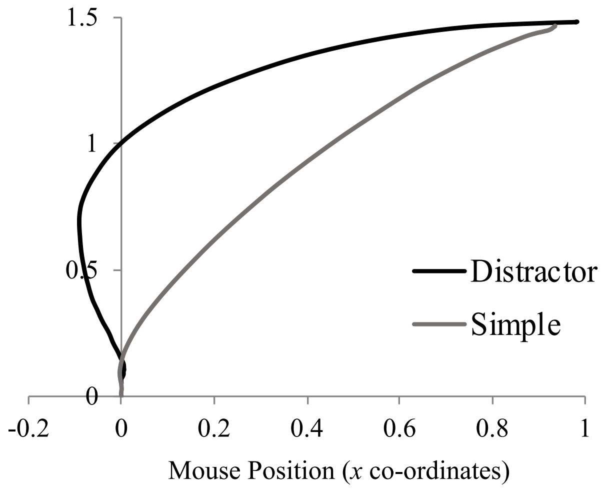
(g) Participant Seven



(h) Participant Eight



(i) Participant Nine



(j) Participant Ten

Figure 3.9. The average response trajectories plotted for each condition for Participant 1, (b) Participant 2, (c) Participant 3, (d) Participant 4, (e) Participant 5, (f) Participant 6, (f) Participant 7, (g) Participant 8, (i) Participant 9, and (j) Participant 10.

As expected, average RT's and initiation times between each participant also differed, Table 3.1 illustrates that on average in each condition, Participant 1 took longest to initiate movement whereas Participant 2 was the quickest. Participant 8 took longer to respond compared to other participants such as Participant 11 who answered in the quickest time.

Table 3.1. The Average Response Time and Initiation Time for Each Participant.

	Simple		**Distractor**	
Participant	Initiation Times	Response Times	Initiation Times	Response Times
1	272	874	277	1072
2	25	797	28	911
3	57	944	52	1053
4	140	1088	134	1097
6	210	1058	196	1129
7	187	790	160	875
8	263	1202	271	1218
9	157	976	159	1063
10	143	734	141	775
11	151	688	153	717

As illustrated in Figure 3.9 (a, b, c, d, e, f, g, h, i, and j), the effect for the distractor condition is less apparent in Participant 8 and as shown in Table 3.1 this participant had the longest response time and the second longest initiation times in both conditions which suggests they had already decided on the options before they selected their response and therefore the time line of the decision making process would not be reflected in the response trajectories. By excluding Participants 8's trials with initiation times longer than 300 ms this removed a further 2.35% of trials from the distractor condition and 9.85% of trials from the simple condition and resulted in Participant eight showing similar trajectories to others between each condition as shown in Figure 3.10. Whilst this demonstrates that there were differences in the condition it also emphasises the importance of asking participants to move their mouse as soon as possible in mouse tracking.

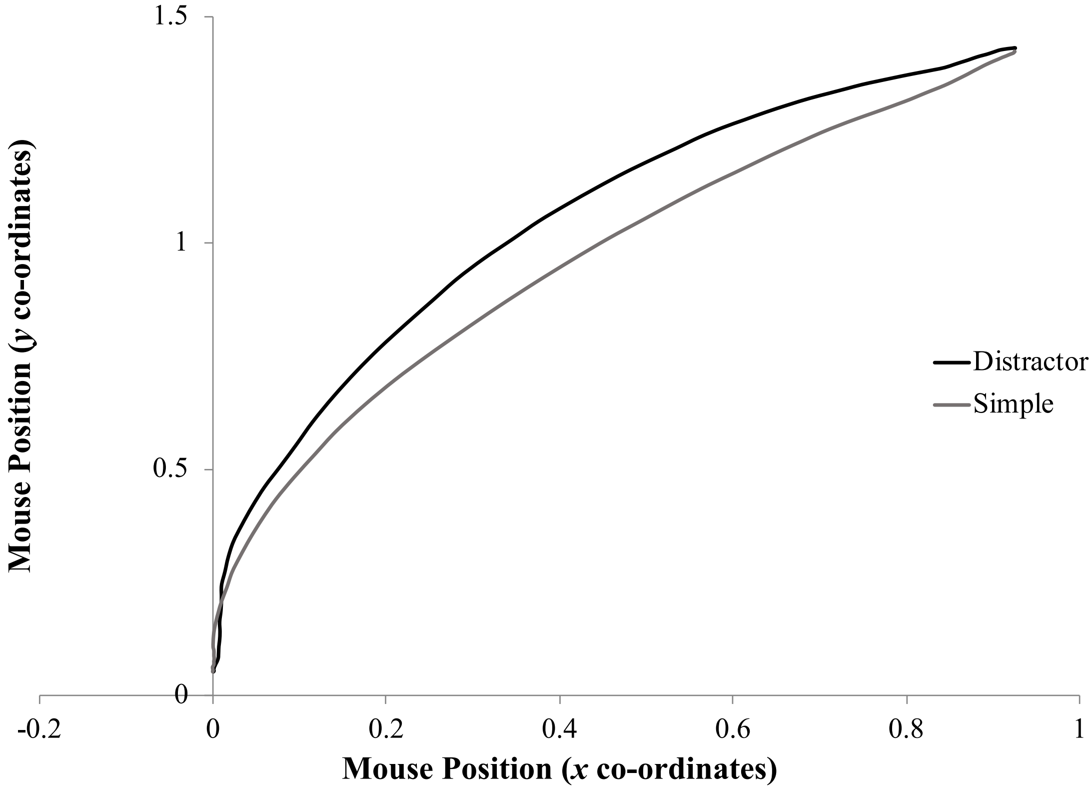


Figure 3.10. The average response trajectory for participant 8 with initiation times restricted from the Simple condition and Distractor condition.

Location and orientation of target. In order to determine whether the location and orientation of the target influenced each condition, the RT's for each condition were recorded for each quadrant in Table 3.2. In the distractor condition, RT's were quickest when the target was located nearer the response button in the upper quadrant and tilting the same way as the response button. This was also the case in the simple condition.

Table 3.2. The Average Response Time for Each Location of Target in Both Conditions.

	Distractor		**Simple**	
Position	Tilted left	Tilted right	Tilted left	Tilted right
Left Upper	887	999	846	918
Left Lower	1005	1020	895	905
Right Upper	971	887	940	847
Right Lower	1004	983	914	910

As shown in Figure 3.11, the trajectory is more direct when the location of the target is the same as the orientation. When the target is tilting left and located on the left the trajectories are shorter. When the target is tilting right and located on the right the trajectories are shorter. This is especially clear in the distractor condition. Similarly, if the target is situated in the upper corner of the screen near the response buttons the trajectory is more direct.

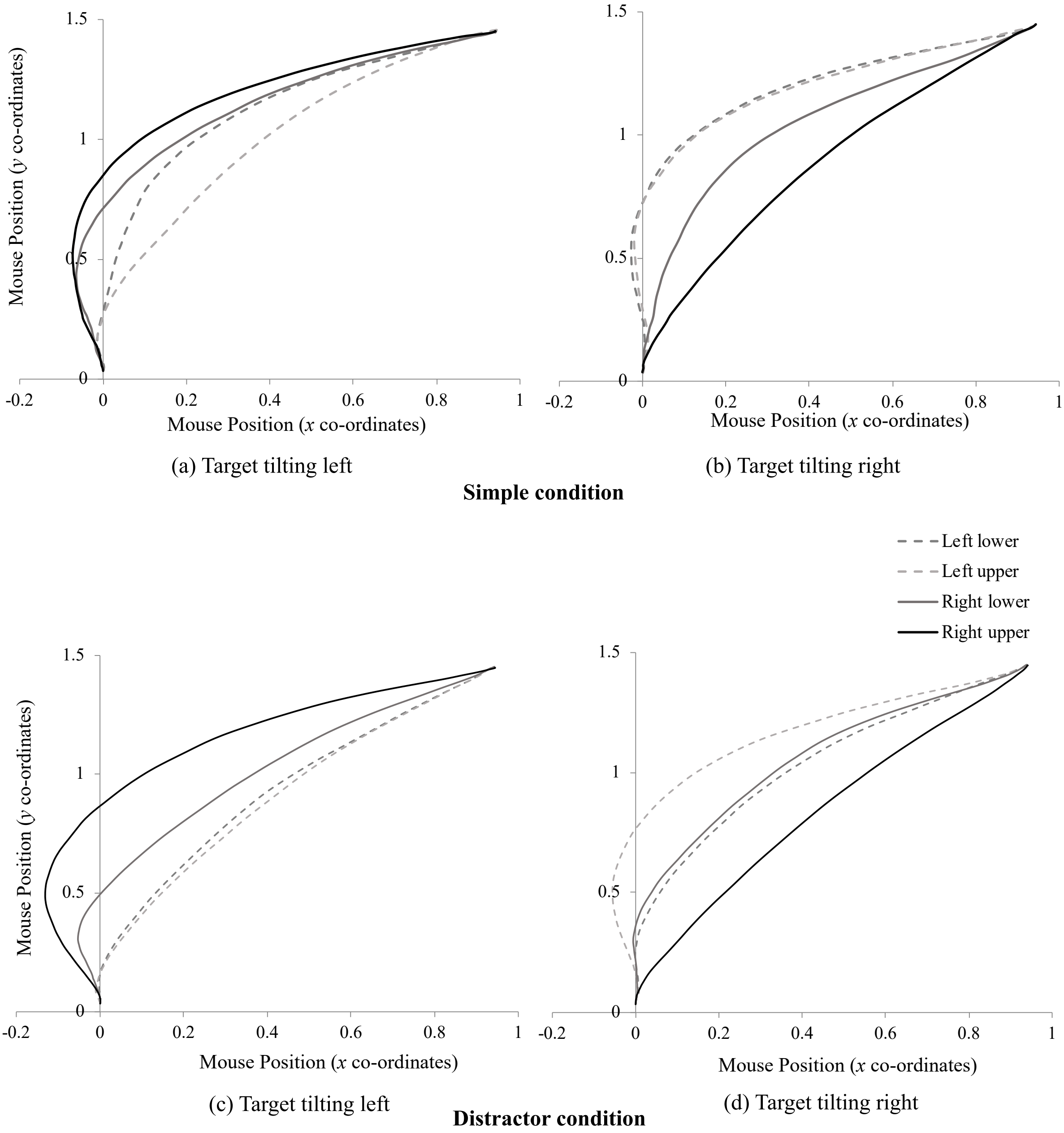


Figure 3.11. The average response trajectory in each condition for each target direction and location.

3.5 Discussion

The results from this experiment replicated the findings of Carrasco and McElree (2001) and Kent et al. (2012), as it is shows that participants are faster and more able to complete visual discrimination tasks when distractors are not present. This also supported previous findings that increasing set size has an effect on visual search efficiency when distractors are included (Treisman & Gelade, 1980; Wolfe, 1994; McElree & Carrasco, 1999).

First, in terms of discrimination/accuracy, there was a significant difference between each condition, more errors were made in the distractor condition. This is similar to Carrasco and McElree (2001) who found that asymptotic discriminability decreased as the set size increase from 1 to 8. This is also consistent with the previous findings described earlier (Verghese & Nakayama, 1994, McElree & Carrasco, 1999).

Second, in terms of RT, when distractors were present RTs were significantly longer. The mouse tracking data was also able to demonstrate that in terms of response trajectories, having additional distractors present resulted in larger response trajectories. This was also reflected in discrete measurements such as the area under the curve and maximum deviation which were significantly higher in the distractor condition compared to the simple condition. These findings are consistent with the findings by Carrasco and McElree (2001), who found that in the neutral conjunction task increasing the set size from 1 to 8 reduced processing speed (as measured by intercept and rate).

Further analysis of individual's response trajectories demonstrated that the differences between the two conditions were consistent participant by participant. It is worth noting the shape of the trajectories is also indicative of the characteristics of hand kinematics. Movement in the hand towards the thumb side of the forearm (radial deviation of wrist) has more degrees of freedom than movement towards the little finger (ulnar deviation of the wrist) (Holzbaur, Murray & Delp, 2005). Therefore, when moving the mouse participants are likely to move the mouse to the left-hand side of the screen. As this occurs in all conditions this is not a confounding factor but should be considered in future studies.

Whilst these findings are often applied to the serial/parallel dichotomy, as described in Chapter 1 interest in this viewpoint has waned and several alternative theories have been presented to explain these findings. Duncan and Humphreys' Similarity Theory (1989) states that attention is drawn to objects not locations and participants performance at visual search tasks are dependent on similarities between objects and distractors. Simply, when heterogenous distractors are present and the similarity between the target and distractors is increased participants are less able to discriminate a target. A flexible model of attention would suggest that the addition of distractors slows information accumulation because attention is shared between more than one object (Kent, Howard, & Gilchrist, 2012).

Models based on Signal Detection Theory (Palmer, Verghese & Paval, 2000) suggests that increased errors are made because the inclusion of distractors effects the internal sensory representation of the target. As the set size increases so does the probability that the noise from the distractor will increase the chances that the target is confused with the distractor (Verghese, 2001; Cameron, Tai, Eckstein & Carrasco, 2003). As shown by the increased number of errors in the distractor condition, the trial by trial trajectories (Figure 3.6) and the maximum deviation distributions, participants in the distractor condition were more likely to consider the alternative option which suggest participants were more likely to confuse the target with distractors. Although an analysis of the movement reversals across the x-axis were not significantly different.

However, in addition to confirming that the addition of distractors impacted search efficiency the results suggest that the location of target impacted response trajectories, contrary to Duncan and Humphrey's Similarity Theory (1989). In standard visual tasks the location of a target is usually randomised across locations within the display and as such they tend to be ignored in data analysis (Wolfe, O'Neill, & Bennett, 1998). However, previous research suggests targets presented near fixation are found more easily compared to items displayed at the periphery, this is known as the eccentricity effect (Carrasco, Evert, Chang, & Katz, 1995). Carrasco, Evert, Chang, and Katz (1995) ran three experiments which manipulated, target orientation, target presence and the set size. When present the target was displayed at either 0.7°, 1.6°,2.1°,2.6°,2.9°, or 3.5° away from the fixation point. In the first experiment, participants were given a free viewing to locate the target and correctly identify its orientation. In the second experiment, display was limited to 104 ms so that participants eye movements were limited, and in the final experiment display was limited to 62 ms to reduce the number of covert attentional shifts that could take place. For all three experiment, RTs, error rates and set size effects increased as eccentricity increased. The authors concluded that given the similarities between all conditions, the eccentricity effect is not mediated by covert attention but occurs because of spatial resolution (sensitivity to fine patterns) and lateral inhibition (stimulated neurons supressing the activity of nearby neurons).

Despite the target being presented in one of four locations equal distance from the fixation cross, the location and orientation of the target in relation to the correct response influenced participants' response trajectories especially when distractors were present. This has two implication, first, when responding participants moved their focus away from the fixation cross towards the response buttons. It is possible eccentricity effects meant that the targets closer to the response buttons were identified more efficiently. This also suggests that when participants are trying to identify targets, they are also considering what response they are likely to make and thus, top down processing is at play. Second, the direction the target was orientating towards moved participants attention towards that side of the screen and the relevant response button. However, it is unclear whether this occurred involuntarily or if participants attempted to use the target as a cue (Chapter 4 will explore the role of targets in discrimination tasks in more detail).

The location and orientation findings presented in this chapter were stronger when the task was more difficult, and distractors were present. Carrasco et al. (1995) raised the possibility that the set size effects could be accelerated by eccentricity effects. Wolfe, O'Neill, and Bennett (1998) ran a series of experiments to explore the role of eccentricity effects in visual search tasks including their role in relation to set size effects. Participants had to detect if a target was present in two tasks, the first was a conjunction search task where distractors varied on colour and orientation. The second task involved a more difficult serial search task where participants searched for a 2 amongst 5, or a mirrored S amongst S's. Targets were displayed in one of 24 locations radiating from the fixation point. Set size was were varied in each task. Replicating the findings by Carrasco et al. (1995) errors and RTs increased as set size and eccentricity increased. The authors also found a correlation between set size and eccentricity for each task, although this interaction between set size and eccentricity was larger for the more difficult serial search compared with the conjunctive search task. Although it is unclear if eccentricity effects and set size effects are independent variables influenced by similar variables or if they directly influence each other; these results are consistent with the finding the location of the target has a larger impact on the visual search task with distractors.

Eccentricity has consequently been suggested as an alternative explanation to set size effect and reflects the growing trend to move away from the traditional serial shifts of attention theories originally proposed by Treisman and Gelade (1980). When more distractors are present the target is more likely to appear in peripheral positions and as such would result in a decrease of spatial resolution. This idea has been supported by subsequent studies; for example, increasing stimulus size in line with eccentricity has been shown to eliminate set-size effects for feature search and reduce set size effects in conjunction search tasks (Carrasco & Frieder, 1997). Similarly, using pre cues and manipulating exogenous attention have been shown to reduce conjunction set size effects (Carrasco & Yeshurun, 1998).

To conclude, mouse tracking was able to replicate the findings from Carrasco and McElree (2001) and from Kent et al.'s (2012) feature search task which both demonstrated that when distractors were present error rates and RT's were higher. In addition to replicating the findings the mouse tracking analysis was also able to provide additional measures such as initiation times, response trajectories (maximum deviation, area under the curve and x-axis reversals) and distribution analyses. These results were achieved without using a SAT paradigm and thus avoided the unnatural format of responding on cue, the requirement for training, the secondary load, and loss of data. It is especially notable that in McElree and Carrasco (1999) experiment, the number of set sizes manipulated were reduced due to the increased length of the response-signal SAT experiment. Furthermore, in order to replicate Carrasco and McElree (2001) feature search task, participants in Kent et al.'s (2012) experiment undertook 16,640 trials, whereas in this experiment they took part in 720 trials. Given mouse tracking has been able to replicate the effects of including distractors into visual search tasks it would be interesting to apply this paradigm to other areas of the literature and focus on the effects of selective attention by introducing cues into the visual search paradigm.

Chapter 4 Mouse tracking and visual processing with cues

4. 1 Chapter Summary

The first part of this chapter will continue to use mouse tracking as a tool to investigate the role of visual attention by focusing on participants performance on a target discrimination task whereby first, the number targets and distractors were manipulated and second, the number of cues manipulated. Based on previous research (Carassco & McElree, 2001), increasing targets and decreasing the number of distractors should decrease speed, error rates and reduce the curvature of response trajectories. By introducing cueing and manipulating covert attention towards the target, based on Carassco & McElree (2001), it would be expected that participants should perform better at the target discrimination task, however, pilot work by Kent and Howard (2010) demonstrated that participants could only attend to one cue at a time. The results demonstrated that increasing the number of targets gradually improved performance at target discrimination. However, increasing the number of cues only improved target discrimination performance in terms of RT's and initiation times when three/four cues were used in the four-target condition. Overall, it appeared participants were ignoring cues as demonstrated in a final analysis where task performance with an informative cue was compared to performance with a non-informative cue.

4.2 Introduction

Chapter 3 demonstrated that by using mouse tracking it was possible to replicate previous findings that including distractors in a visual discrimination task hinders how attention is allocated to finding a target. Specifically, the results replicated the findings from previous Speed-accuracy trade-off (SAT) experiments but without any of the methodological problems associated with the SAT paradigm. It would therefore be interesting to apply this technique to investigate how manipulating selective attention affects visual search task performance. Spatial attention can be manipulated either overtly and gaze is directed towards a specific location through eye movements; or covertly where gaze is centrally fixed, but attention is drawn to a location in the periphery, as initially explored in Chapter 2 (Posner, 1980).

Experimental evidence suggests covert attention is a particularly useful tool when processing our visual environment, as demonstrated in tasks which look at contrast sensitivity, it can aid perception by reducing uncertainty. Prinzmetal, Amiri, Allen, and

Edwards (1998) used a dual task paradigm, whereby participants had to match the colour of a dot presented on either side of the screen to a colour on a central palette. In order to manipulate attention, participants were given a second task identifying whether a centrally located letter matrix contained an ‘F’ or ‘T’, this was either presented at the same time or after the colour identification task. When participants were able to focus attention solely on the colour identification tasks the variability in responses decreased i.e. participants were able to pick the precise colour shade (e.g., ‘chartreuse’) rather than the colour group (e.g., ‘green’). They concluded that the reduced variability meant that attention reduced the uncertainty of the information about the stimulus.

Covert attention can also help filter irrelevant material. Lu, Lesmes and Dosher (2002) asked participants to identify the orientation of a pseudo-character (a rotated ‘T’) which was pre-cued by an arrow to one of four locations. In 16 experimental conditions they manipulated external noise, the number of stimuli displayed, the number of locations masked by noise and the number and the style of frames surrounding the target location. They found pre cueing significantly improved participants’ ability to correctly identify the orientation of the target when there was a high presence of external noise. They concluded that covert attention helps filter out task irrelevant stimuli.

Covert attention can improve our ability to discriminate spatial resolution. Spatial resolution refers to our ability to determine fine patterns, a skill which is use in a variety of tasks, whilst best at the focus of our gaze it diminishes towards the periphery of our visual field, also known as eccentricity (Carrasco & Barbot, 2014). Covert attention has been shown to improve our abilities at a variety of spatial resolution tasks such as acuity and texture segmentation. Acuity refers to a measure of how well participants are able to identify fine detail, it is required for a variety of tasks such as target detection involving finding the location of the gap in a Landolt task, target localisation involving discriminating differences in the spatial portion of an object such as a break in a line (also known as Vernier acuity) or target recognition correctly identifying a letter of the alphabet (Snellen, 1862). Yeshurun and Carrasco (1999) ran three experiments, in the first experiment participants were given a two alternative forced choice task and asked to identify which side the gap appeared on a Landolt square; in the second experiment, participants were asked to detect whether a gap was present and in the third experiment, participants were given a Vernier task and asked to indicate whether the upper line was displaced to left or right of the lower line. In all three conditions performance decreased with eccentricity. However, using a pre cue improved participants RT’s and accuracy.

Whilst spatial resolution is a useful tool for detecting fine details, in some circumstances it can actually hinder performance such as when a global view is required for example, when viewing an impressionist painting (Carrasco 2011). In these circumstances, there will be a resulting decreased performance at the attended location. To address this a texture segmentation task can be used, in which a target texture, lines orientated at 45° is embedded into a larger background of lines whose orientation is orthogonal to the target (Yeshrun & Carrasco, 1998). Participants perform better at the task when the target was presented mid-peripherally compared to when it appears at the centre or peripheral (Carrasco, 2011). Cueing has been found to improve participants abilities at the task. Enhancing spatial resolution using an exogenous cue (a green horizontal bar above the target location) compared with neutral cue (two horizontal lines appearing above and below the stimulus display) has been found to increase accuracy at the periphery where spatial resolution is low whilst impairing performance at central locations where resolution is high (Yeshurun & Carrasco, 1998; Yeshurun & Carrasco, 2000). Using an endogenous cue (a digit and a line) also improved accuracy at the periphery but unlike exogenous cues improved accuracy at central locations (Yeshurun, Montagna & Carrasco, 2008).

Another example of a spatial resolution task is visual search where a participant must identify a target. To investigate if attention can enhance spatial resolution covert attention is again manipulated through the introduction of cues. Covert attention has been shown to increase the speed in which objects from a visual search task are processed. The Carrasco and McElree (2001) experiment replicated in Chapter 5 also manipulated covert attention by using cues to see the effects on processing speed. Cues were used to indicate a target location and were either peripheral or neutral (as used in Chapter 5). Participants were asked to identify whether a target, a 2-cpd Gabor patch, was tilted to the right or left. Set size was also manipulated from 1 target and no distractors, 1 target and 3 distractors or 1 target and 7 distractors. Plotting SAT curves demonstrated that manipulating covert attention through peripheral cueing improved participants ability at locating the target, as measured by asymptotic accuracy and also accelerated information processing, as measured by intercept and rate, in both feature search tasks and conjunction search task.

Based on pilot work by Kent and Howard (2010) which attempted to address how resources are allocated within the visual field using a SAT paradigm. Using the same experimental set up as Kent, Howard and Gilchrist (2012) described in Chapter 3, participants had to discriminate whether a Gabor patch was tilting to the left or right of the screen. Either one valid cue or four (non-diagnostic) cues were presented and the number of targets were manipulated whilst RT's were recorded. The preliminary results showed that when all the target locations were cued participants were faster at detecting the target as the number of targets increased. When only one cue was used increasing the number of targets did not impact accuracy or discriminability. Another preliminary experiment manipulated the number of cues used for each trial. Two participants completed a SAT paradigm and for three participants, free RT's were recorded. In all trials, four targets were presented with either one, two, three, or four cues or a non-informative central cue. Interestingly, the preliminary data showed that having one cue improved target discrimination and accuracy compared to using either two, three, or four cues although these accuracy rates were still higher than using a central cue. Both these preliminary studies suggest participants only had enough attentional capacity to attend to one valid cue effectively and performed the task better compared to when attention was split across multiple cues.

In order to explore how much attentional spare capacity is available to utilise information from other sources, both the number of cues and targets will be manipulated in a conjunction search task whereby participants must discriminate the orientation of a target. First, the experiment will investigate the effect of increasing targets and decreasing distractors when using a neutral cue. Based on set size effects from previous research (Carassco & McElree, 2001) and the preliminary work from Kent and Howard (2010) it would be expected that when using a non-informative cue there should be spare capacity to utilise the information from the increasing number of targets and decreasing distractors. As such we would expect the increase in targets not only to result in shorter RT's but also in direct response trajectories and the smaller AUC and MD.

The second analysis will focus on how much spare attentional capacity is available to utilise information from varying numbers of cues and the effect of increasing the number of cues present across two, three, and four targets has on target discrimination. Based on Kent and Howard (2010) it would be expected that as participants demonstrates an ability to only attend to one cue effectively having fewer cues improves target discrimination and accuracy, compared to when attention is split across multiple cues. Therefore, smaller number of cues should result in shorter RT's and a direct response trajectory (and smaller AUC and MD).

The third analysis will focus on comparing a single informative cue with a non-informative cue. It would be expected that participants are more efficient at locating the target when using an informative cue and that based on Kent and Howard's (2010) preliminary study increasing targets will have more of an impact for the non-informative cue compared to the single informative cue.

4.3 Methods

Participants. Fifteen undergraduate students (11 female) aged between 18 and 32 took part in the experiment, for course credit. All participants had normal or corrected-to normal vision.

Materials and stimuli. Stimuli were displayed on a 15.4inch laptop screen with resolution of 1,280 x 800 pixel and 60Hz refresh rate. The stimuli were presented in a darkened room. Participants sat approximately 50 cm from the screen and had to move a cordless mouse placed on the right-hand side of the laptop to respond.

Each stimulus consisted of Gabor patches (suprathreshold sinusoidal gratings vignette by a Gaussian envelope) that varied on two dimensions, orientation and spatial frequency. The target was a 2 cycle per degree (cpd) Gabor patch that was tilted to the right or left. The distractors were either an 8 cpd Gabor patch (spatial frequency) tilted to the same degree or a vertical 2 cpd Gabor patch (orientation). A cue consisted of a black circle (20 px x 20 px) which appeared before the targets (50 px x 50 px). For each trial, stimuli were presented in a grid format at a location equidistance from the centre of the screen (co-ordinates 320 px, 200 px; co-ordinates 320 px, 600 px; co-ordinates 960 px, 200 px and co-ordinates 960 px, 600 px).

The MouseTracker space represents a 2 x 1.5 rectangle, the start button and start of all response trajectories was located in the bottom centre of the screen (co-ordinates 640 px, 0 px). One response button (160 px x 256 px) was located at the top left-hand side of the screen (co-ordinates 0 px, 800 px) and the other response button was located at the top right-hand side of the screen (co-ordinates 1024 px, 800 px).

Procedure. As with Experiment 3, participants were asked to identify whether a target was tilting towards the left or right. The same timings were also used whereby a fixation point appeared on screen for 1,000 ms, a pre cue appeared for 67 ms and the stimuli set containing the target was displayed for 50 ms. However, unlike experiment 3 before each target appeared participants were presented with a valid cue to indicate the location of the target(s).

Participants started each trial by clicking the START button in the bottom centre of the screen and moved their mouse to the top left hand button if they believed it tilted to the left and the top right hand button if they believed it tilted to the right. If the incorrect direction was chosen a red cross appeared on screen and if no response was given within 3,000 ms a ‘Time Out’ message appeared. If participants did not initiate their mouse as soon as the targets appeared a dialogue box appeared with the message ‘Move your mouse as soon as the responses appear!’.

Design. The number of cues that appeared on screen varied. There were either 1, 2, 3, or 4 valid cues or a neutral cue was presented in the centre of the screen. Then a total of 4 Gabor patches were presented. However, the number of targets varied. There were either 1, 2, 3 or 4 targets present on the screen amongst either 3, 2, 1 or no distractors respectively. Trials were presented in a random order.

As a result of varying the number of cues and the number of targets there was a total of 14 different conditions, in a non-nested design (see Table 4.1). In total, participants took part in 672 trials, as the target was presented 24 times in each condition and whether the target was left, or right tilting was also counterbalanced.

Table 4.1. The Number of Cues and Targets in Each of the 14 Different Conditions.

	Targets			
	1	2	3	4
Cues				
Central	X	X	X	X
1	X	X	X	X
2		X	X	X
3			X	X
4				X

4.4 Results

Data preparation. One participant was removed from the analysis as 51.29% of their trials were incorrect, suggesting they did not fully understand the task. After the removal of the participant error rates were calculated for each condition before further exclusion were made as shown in Table 4.2. As number of targets increased error rates decreased, however there was no consistent pattern found when increasing number of cues.

Table 4.2. The Percentage of Errors Made for Each Condition After the Removal of Participant.

	Targets			
	1	2	3	4
Cues				
Central	7.14	5.95	2.68	1.19
1	4.91	3.87	2.38	1.34
2		5.21	1.34	2.53
3			2.38	1.04
4				5.06

As participants were required to respond quickly, trials initiated later than 500 ms, RT's longer than 2,000 ms as well as trials where participants failed to response and incorrect trials were also excluded resulting in total of 9.38% of trials being excluded (see Table 4.3 for the exclusions rates per condition).

Table 4.3. The Percentage of Exclusions Made in Each of the Conditions.

	Targets			
	1	2	3	4
Cues				
Central	11.90	10.57	5.95	4.02
1	8.04	7.14	4.91	2.98
2		8.63	3.42	5.36
3			5.95	2.23
4				6.99

4.5 Analysis: overview across all conditions

Response and initiation times. As shown in Table 4.4, RT's became faster as targets increased, however increasing cues did not appear to consistently reduce RT's. Initiation times decreased as target number increased and number of cues increased suggesting participants were more confident in their responses from the outset.

Table 4.4. The Mean Response Times (ms) and Initiation Times (ms) in Each Condition.

	Targets			
	1	2	3	4
Cues				
Central				
Initiation time	200	189	188	183
Response time	1008	973	926	893
1				
Initiation time	184	172	178	175
Response time	985	954	922	893
2				
Initiation time		163	160	165
Response time		952	918	891
3				
Initiation time			155	157
Response time			909	869
4				
Initiation time				160
Response time				874

Maximum deviation and area under the curve. Table 4.5 demonstrates that the maximum deviation decreased as the number of targets increased however, increasing cues did not appear to consistently reduce maximum deviation. Correspondingly the area under the curve also decreased as the number of targets increased, but this pattern did not occur when the number of cues increased.

Table 4.5. The Mean Maximum Deviation and Area Under the Curve For All Individual Conditions.

	Targets			
	1	2	3	4
Cues				
Central				
Maximum deviation	0.33	0.25	0.20	0.15
Area under the curve	0.71	0.51	0.39	0.26
1				
Maximum deviation	0.34	0.29	0.23	0.20
Area under the curve	0.71	0.59	0.48	0.40
2				
Maximum deviation		0.26	0.24	0.20
Area under the curve		0.53	0.50	0.39
3				
Maximum deviation			0.24	0.13
Area under the curve			0.46	0.25
4				
Maximum deviation				0.15
Area under the curve				0.30

4.6 Data analysis: effect of increasing number of targets/decreasing number of distractors

To investigate the effect of increasing targets, the effect on increasing targets with a central **neutral** cue was examined in more detail, as summarised in Table 4.6.

Table 4.6. Means and Standard Deviation (SD) of Initiation Time (ms), Response time (ms), Maximum Deviation, and Area Under the Curve for a Central Cue as Target Increases.

	Targets			
Central cue	1	2	3	4
Response time				
Mean	1008	973	926	893
SD	170	170	178	182
Initiation time				
Mean	200	189	188	183
SD	87	80	81	79
Maximum Deviation				
Mean	0.33	0.25	0.20	0.15
SD	0.23	0.17	0.20	0.17
Area under the curve				
Mean	0.71	0.51	0.39	0.26
SD	0.52	0.38	0.40	0.34
x-flips				
Mean	7.02	6.77	6.71	6.40
SD	1.33	1.60	1.73	1.81

Response and initiation times. As shown in Table 4.6 participants were able to locate a target faster as the number of targets increased. A repeated measures ANOVA showed that ANOVA demonstrated there was an effect of targets on RT's, $F(3,39) = 34.34$, $p < 0.01$; $\eta p2 = 0.73$. Please note where sphericity has been violated the uncorrected degrees of freedom will be reported. Participants were also able to initiate movements quicker when the number of targets increased A repeated measures ANOVA showed that there was an effect of target on initiation times, $F(3,39) = 3.89$, $p < 0.05$, $\eta p2 = 0.23$. This is surprising given participants were expected to move their mouse as soon as possible and initiation times overall are quick.

Response trajectories. As shown in Figure 4.1 (a, b, c and d), as the number of targets increase the curvature of the trajectory response movements become more direct. By plotting each trajectory from all trials in a condition it is also possible to see that as the number of targets increased, less participants moved towards the incorrect response button (Figure 4.2, a, b, c and d). Although it is worth noting that there were little differences between Target 2 and Target 3. The levels of uncertainty also decreased as the number of targets increased as shown by studying the reversal of movement along the x-axis (Table 4.6: x-flips). A repeated measures ANOVA demonstrated an effect of target, $F(3, 39) = 3.77$, $p < 0.05$, $\eta p2 = 0.23$.

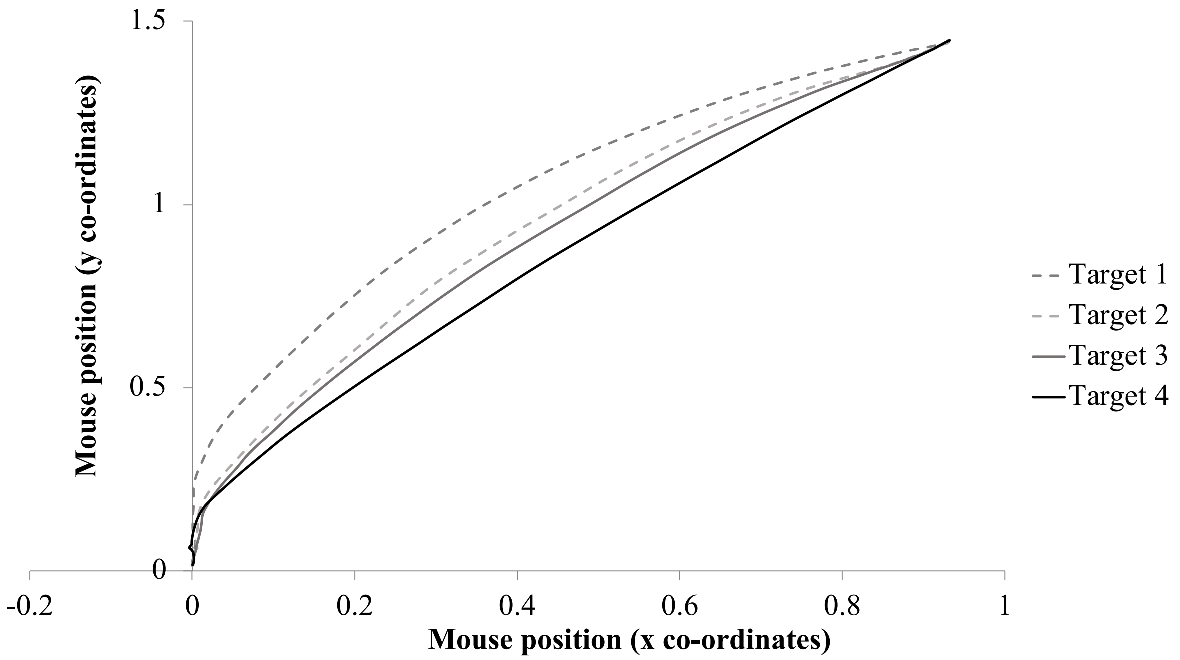
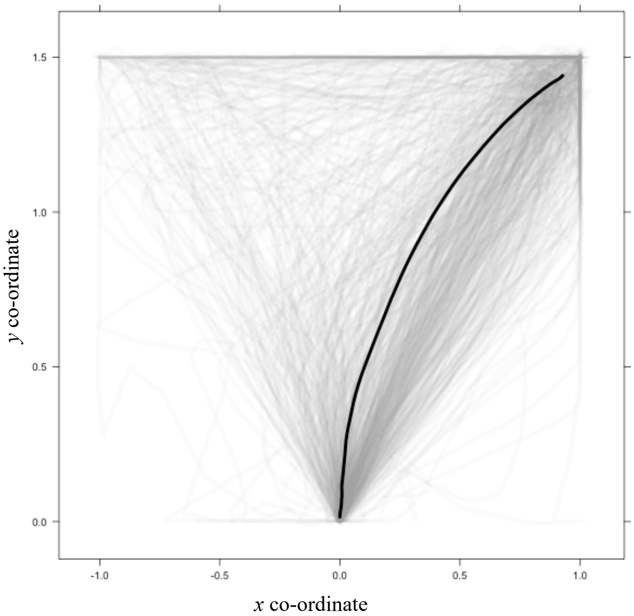
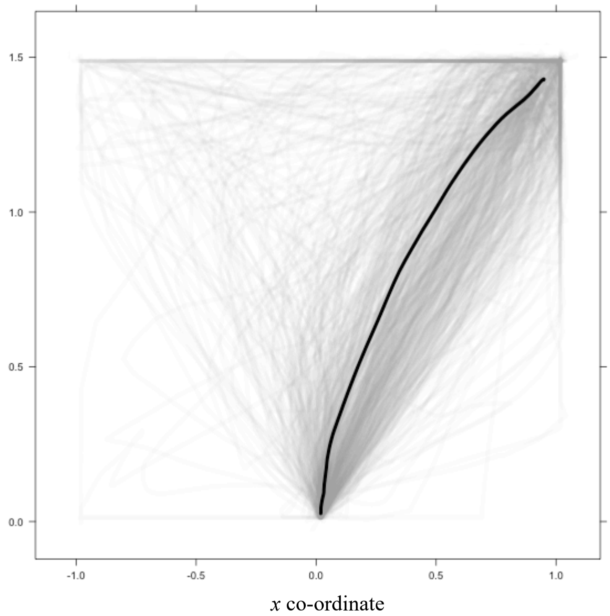


Figure 4.1. The average response trajectory when a Neutral Cue was presented with increasing number of targets: (a) 1 Target, (b) 2 Targets, (c) 3 Targets and (d) 4 Targets.

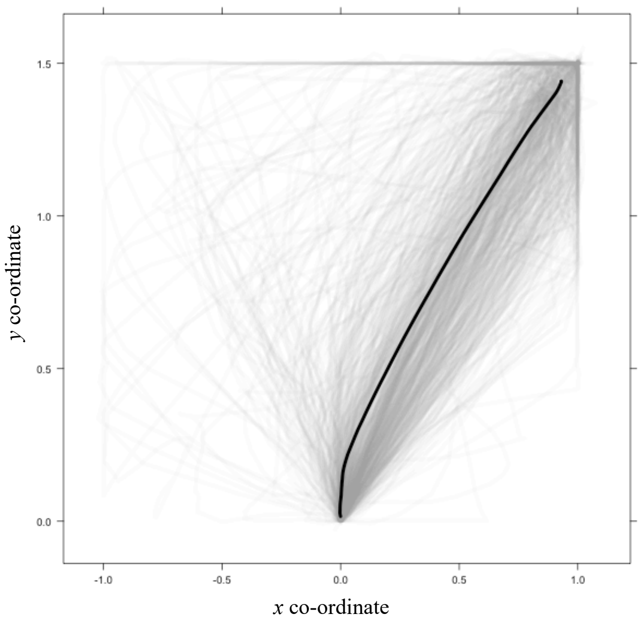
Maximum deviation and area under the curve. Consistent with increased curvature in the response trajectories (Figure 4.1) and as shown in the Table 4.6, as the number of targets increased maximum deviation decreased. A repeated measures ANOVA an effect of target conditions on maximum deviation, $F(3,39) = 17.35$, $p < 0.01$, $\eta p2 = 0.69$. Correspondingly, as shown in Table 4.6, as targets increased in number the area under the curve decreased. A repeated measures ANOVA showed an effect of target conditions on area under the curve, $F(3, 39) = 17.81$, $p < 0.01$, $\eta p2 = 0.58$.



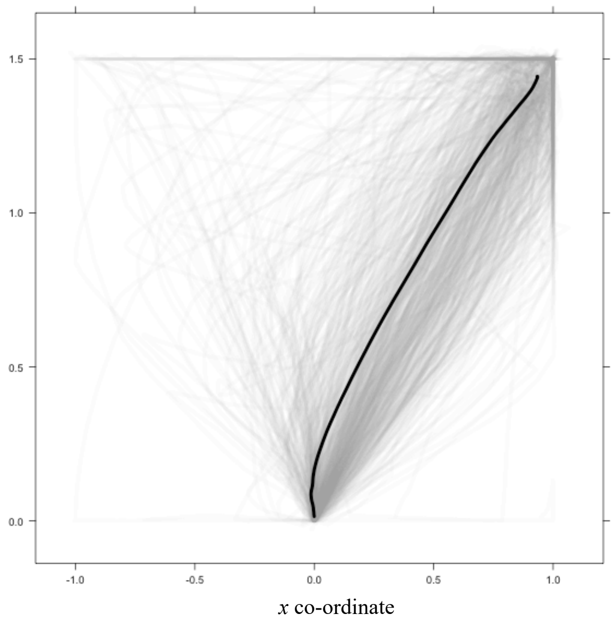
(a) One Target



(a) Two Targets



(a) Three Targets

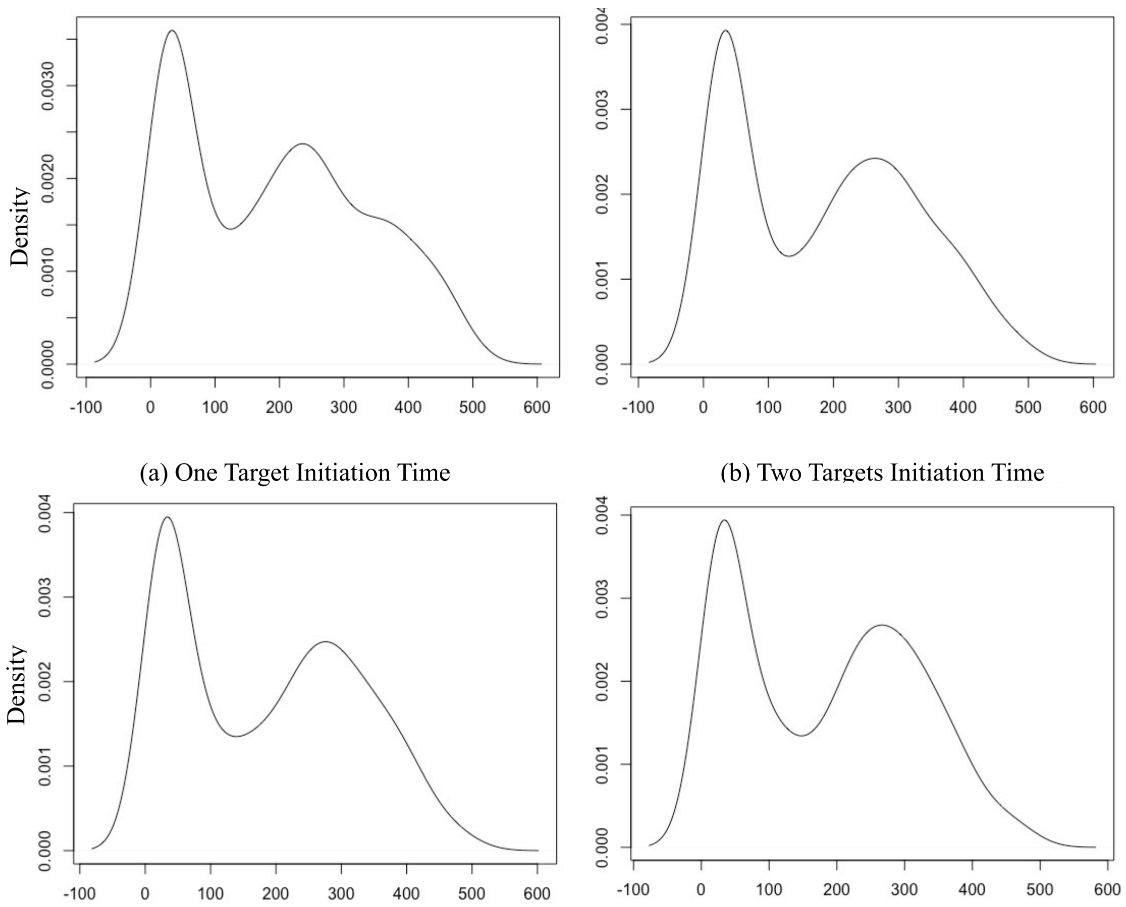


(a) Four Targets

Figure 4.2. All response trajectories for a trial, each line represents a response trajectory from the 'Start' button to response button for an increasing number of targets: (a) 1 Target, (b) 2 Targets, (c) 3 Targets and (d) 4 Targets. The heavy black line represents the mean response trajectory.

Distributions. As shown in Figure 4.3 (a, b, c and d), initiation times were similar across conditions, where the majority of responses occurred in the first 100 ms and a second peak occurring between 200-300 ms. Bimodality across conditions was confirmed by Hartigans dip test; for the Target 1 condition, D =0.06, $p < 0.01$, for the Target 2 condition D =0.06, $p < 0.01$, for the Target 3 condition, D =0.07, $p < 0.01$, and for Target 4 condition D = 0.06, $p < 0.01$. As mentioned in the previous experiment, bimodality in initiation times could simply reflect the design of the MouseTracker software which starts recording initiation times from a nudge or regrip of a mouse. Given this appears across all conditions and participants it is therefore unlikely to be driven by the conditions themselves.

As shown in Figure 4.4 (a, b, c and d), there was a higher number of larger maximum deviations (right tail) in the Target 1 and Target 2 conditions. Freeman and Dale (2013) suggest when there is a large distance between two mean responses such as in these trials, a number of response movements were made towards the incorrect option. Two peaks also form on the left tail in Target 3 and Target 4 conditions, although similar to the Simple condition in Experiment 3, these distributions could reflect differences in hand kinematics. When the correct answer is on the right-hand side radial movements towards the left (negative MD) may become more frequent in faster responses. These distributions are reflected in the Hartigans' dip test which were significant for all conditions, for Target 1 condition, $D = 0.08$, $p < .001$, for the Target 2 condition $D = 0.06$ $p < .001$, Target 3 condition, $D = 0.03$, $p < .001$, and for Target 4 condition $D = 0.04$, $p < .001$. This bimodality however is not apparent in the distributions for area under the curve as shown in Figure 4.5 (a, b, c and d); distributions are similar in all conditions with a large number of smaller areas under the curve and fluctuating amounts in the right tail.



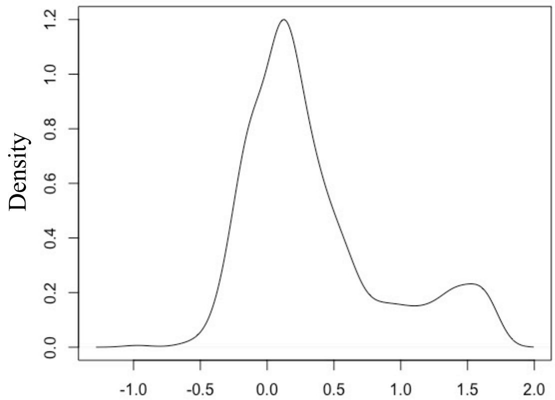
(a) One Target Initiation Time

(b) Two Targets Initiation Time

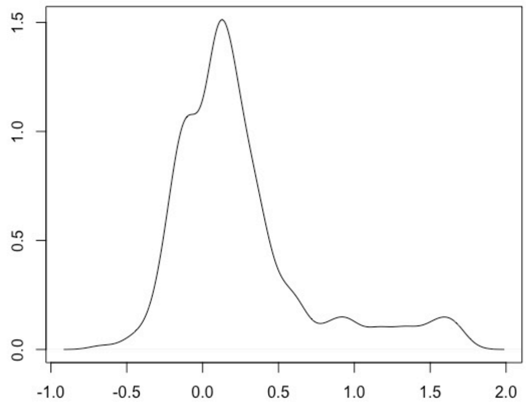
(c) Three Targets Initiation Time

(d) Four Targets Initiation Time

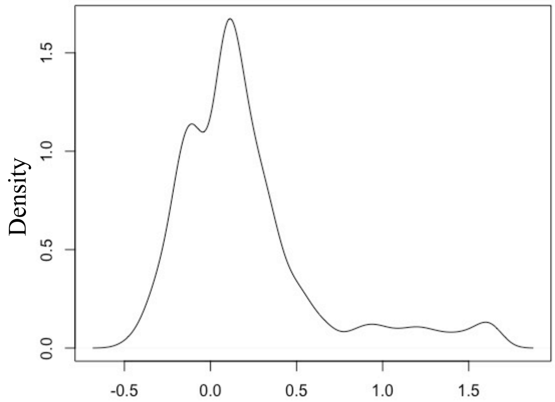
Figure 4.3. Distributions of Initiation Times for a neutral Cue and an increasing number of targets: (a) 1 Target, (b) 2 Targets, (c) 3 Targets and (d) 4 Targets.



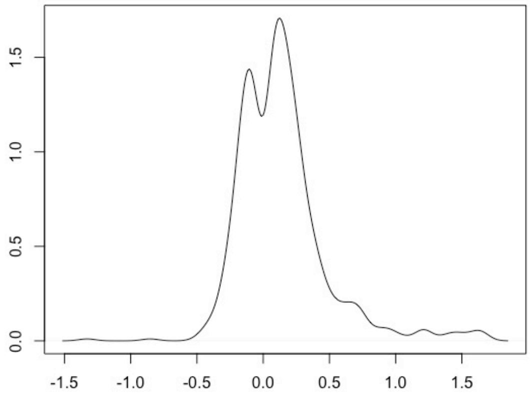
(a) One Target Maximum Deviation



(b) Two Targets Maximum Deviation

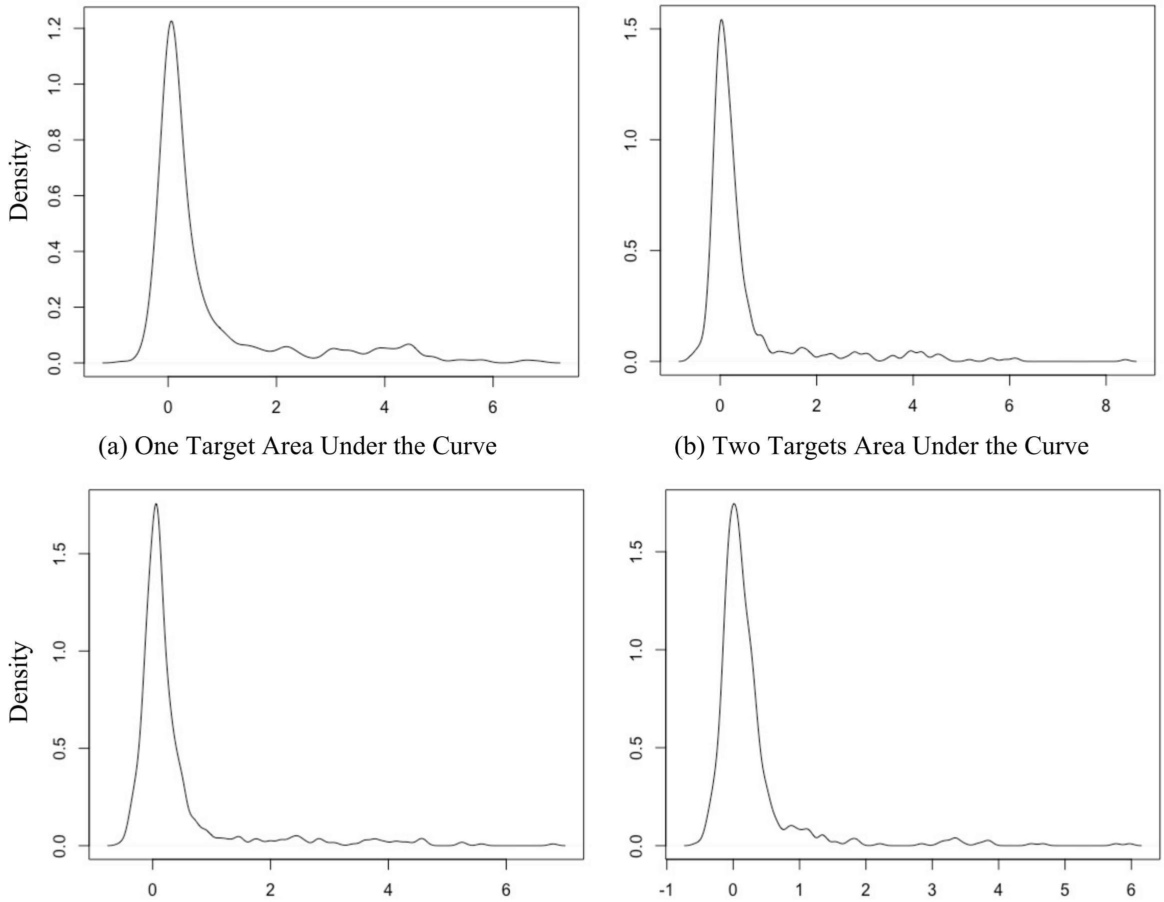


(c) Three Targets Maximum Deviation



(d) Four Targets Maximum Deviation

Figure 4.4. Distributions of maximum deviation for a neutral cue and an increasing number of targets: (a) 1 Target, (b) 2 Targets, (c) 3 Targets and (d) 4 Targets.



(a) One Target Area Under the Curve
(b) Two Targets Area Under the Curve
(c) Three Targets Area Under the Curve
(d) Four Targets Area Under the Curve

Figure 4.5. Distributions of area under the curve for a neutral cue and an increasing number of targets: (a) 1 Target, (b) 2 Targets, (c) 3 Targets and (d) 4 Targets.

To conclude, increasing the number of targets and decreasing the number of distractors improved participants ability to undertake target discrimination as demonstrated by reduced RT's, response trajectory curvature, reduced maximum deviation and reduced area under the curve.

4.7 Data analysis: effect of increasing the number of cues across each target condition

In order to address how cues effect targets, the effect of increasing cues will be analysed for each of the 2, 3, and 4 target conditions.

4.7.1 Two-target condition

The following analysis will study how increasing the number of cues from one to two cues affects target discrimination in the two-target condition.

Response and initiation times. As shown in Table 4.7, increasing the number of cues from one cue to two cues resulted in similar RT's. A paired sample t-test revealed cues did not impact how fast a participant responded. The average response time for the one cue condition was not significantly different when two cues were used; 95% CI [-22.63 to 26.20] $t(13) = 0.16$, $p > 0.05$, $d = 0.04$.

As shown in Table 4.7, participants were able to move their mouse as soon as possible regardless of the number of cues, as shown by similar initiation times in both conditions. A paired sample t-test confirmed the average initiation time for the one cue condition was not significantly different to the two cues condition; 95% CI [-0.94 to 19.55] $t(13) = 1.96$, $p > 0.05$, $d = 0.51$.

Table 4.7. The Mean and Standard Deviation (SD) of Response time (RT), Initiation Time (IT), Maximum Deviation (MD), Area Under the Curve (AUC) and *x*-flips for Two Targets and One and Two Cues.

Two Targets	RT		IT		MD		AUC		*x*-flips	
Cues	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	954	185	172	82	0.29	0.20	0.59	0.45	6.65	1.42
2	952	196	163	80	0.26	0.20	0.53	0.43	6.72	1.47

Response trajectories. As shown in Figure 4.6, although the response trajectories were most direct in the two-cue condition, the response trajectories had a similar form in each condition. These similarities are also reflected in Figure 4.7 (a, and b), where each individual trajectory has been plotted for each trial in both conditions. A change in cue conditions also resulted in comparable responses when the average number of reversals along the x-axis were counted (Table 4.7: x-flips). A paired sample t-test demonstrated there was no significant difference between one cue condition and the two cue condition, 95% CI [-0.31 to 0.15], $t(13) = -0.76$, $p > 0.05$, $d = 0.20$.

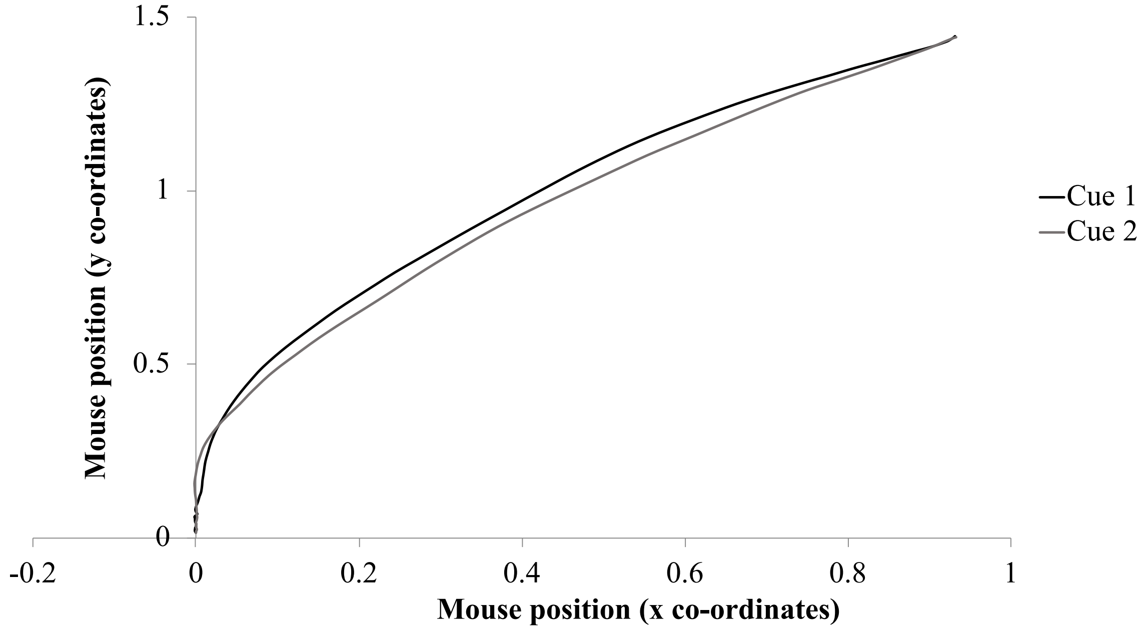
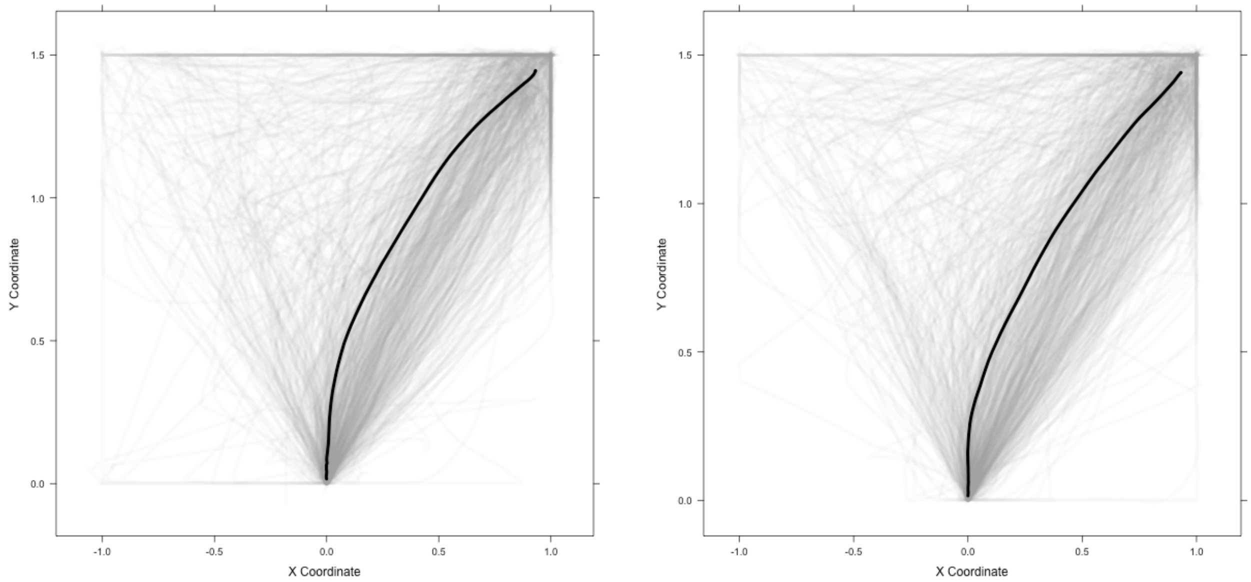


Figure 4.6. The average response trajectory for the two-target condition as the number of cues were increased from one cue to two cues.



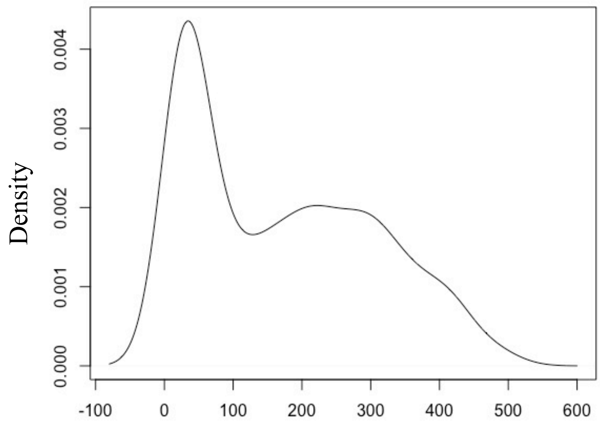
(a) One cue (a) Two cues

Figure 4.7. All response trajectories from each trial, each line represents a response trajectory from the 'Start' button to response button for (a) One cue and (b) Two cues. The heavy black line represents the mean response trajectory.

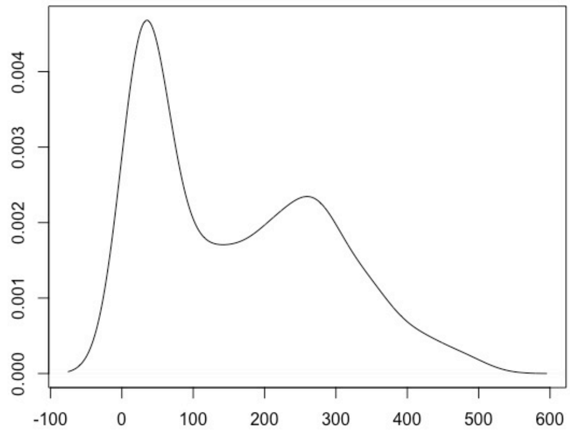
Maximum deviation. Consistent with the response trajectories presented in Figure 4.6 the maximum deviation was only marginally smaller when 2 cues were used (Table 4.7). A paired sample t-test revealed the difference between one cue and two cues was not significant; 95% CI [-0.31 to 0.96] $t(13) = 1.12$, $p > 0.05$, $d = 0.30$.

Area under the curve. As expected from the above findings, a paired sample t-test confirmed there was no significant difference when one cue and two cues were presented; 95% CI [-0.06 to -0.07] $t(13) = 0.97$, $p > 0.05$, $d = 0.25$.

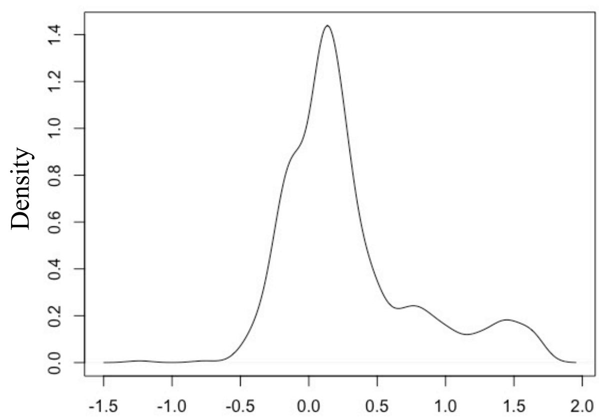
Distributions. As shown Figure 4.8 (a, and b), distributions for initiation times were similar in both conditions, where the majority of responses occurred in the first 100 ms and a second peak occurring between 200-300 ms. For initiation time, a bimodal tendency was confirmed in both conditions by Hartigans' dip test in the one cue condition $D = 0.06$, $p < 0.05$ and the two-cue condition $D = 0.08$, $p < 0.05$. This distribution reflects how participants are encouraged to move the mouse as soon as possible in both conditions and is not driven by the conditions themselves.



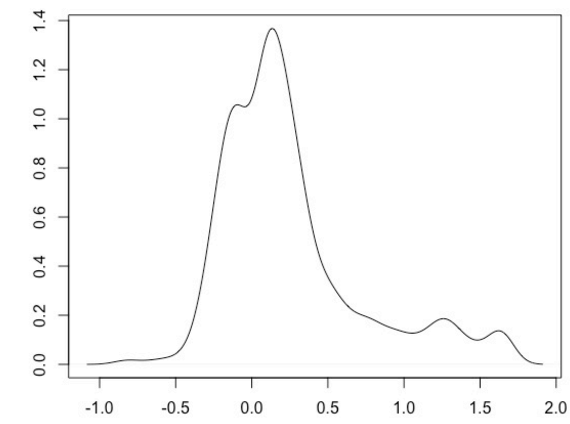
(a) One Cue Initiation Time



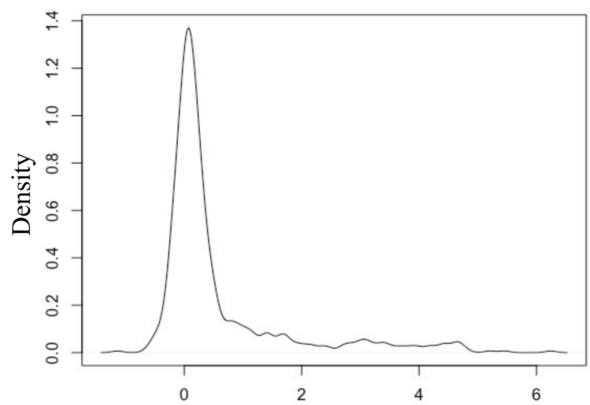
(b) Two Cues Initiation Time



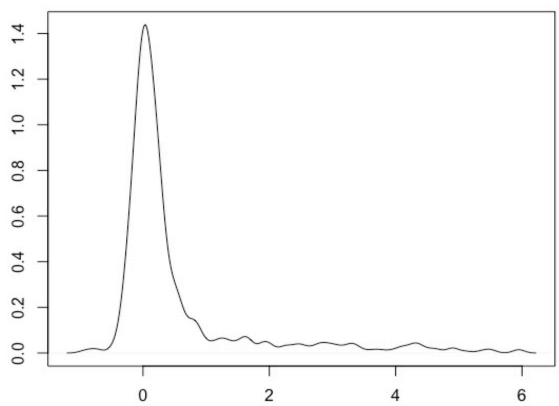
(c) One Cue Maximum Deviation



(d) Two Cues Maximum Deviation



(e) One Cue Area under the curve



(f) Two Cues Area under the curve

Figure 4.8. Distributions across conditions (a, c, and e) One cue and (b, d, and f) Two cues for initiation times (a and b), maximum deviation (c and d) and area under the curve (e and f).

Distributions for maximum deviation (Figure 4.8, b and c), also did not differ across conditions. In the left tail, there was evidence of an additional peak forming (which as stated previously may relate to hand kinematics) and in the right tail, a higher number of larger maximum deviations (Figure 4.7, c and d). Hartigans' dip test confirmed there was a bimodal tendency in both conditions; in the one cue condition $D = 0.05$, $p < 0.05$ and the two-cue condition $D = 0.05$, $p < 0.05$. This suggests that in both conditions participants responses involved some movement towards the alternative option, however as this appears in both conditions it is not driven by the conditions themselves. This bimodality is not evident in the distributions for area under the curve, as shown in Figure 4.8 (e and f); distributions are also similar in both conditions and peaks initially before distribution rises and dips on the right tail.

To conclude, the RT's and mouse tracking data suggests that increasing the number of cues from one to two does not impact participants abilities in target discrimination when two targets are present.

4.7.2 Three-target condition

The following analysis will investigate how increasing the number of cues from one to two to three cues affects target discrimination in the three-target condition.

Response and initiation times. As shown in Table 4.8, increasing the number of cues resulted in decreased RT's. However, a repeated measures ANOVA demonstrated there was no effect of cues on the RT's, $F(2,26) = 0.71$, $p > 0.05$; $\eta p2 = 0.05$.

As shown in Table 4.8, participants were able to initiate response trajectories faster as the number of cues increase. A repeated measures ANOVA showed an effect of cues on initiation times, $F(2,26) = 7.32$, $p < 0.05$; $\eta p2 = 0.36$.

Table 4.8. The Means and Standard Deviations (SD) of Response time (RT), Initiation Time (IT), Maximum Deviation (MD, Area Under the Curve (AUC) and *x*-flips for Three Targets and One, Two and Three Cues

Three Targets

	RT		IT		MD		AUC		*x*-flips	
Cues	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	922	195	178	88	0.23	0.23	0.48	0.58	6.48	1.65
2	918	174	160	81	0.24	0.21	0.50	0.50	6.58	1.69
3	909	172	155	72	0.24	0.21	0.46	0.42	6.74	1.61

Response trajectories. As shown in Figure 4.9, although the response trajectories were initially different in the three cues condition, overall the response trajectories had a similar form in each condition. These similarities are also reflected in Figure 4.10 (a, b, and c), where each individual trajectory has been plotted for each trial in both conditions. A change in cue conditions also resulted in comparable responses when the average number of reversals along the x-axis were counted (Table 4.8: *x*-flips). A repeated measures ANOVA confirmed there was no effect of cues on x-flips, $F(2,26) = 1.20$, $p > 0.05$; $\eta p2 = 0.09$.

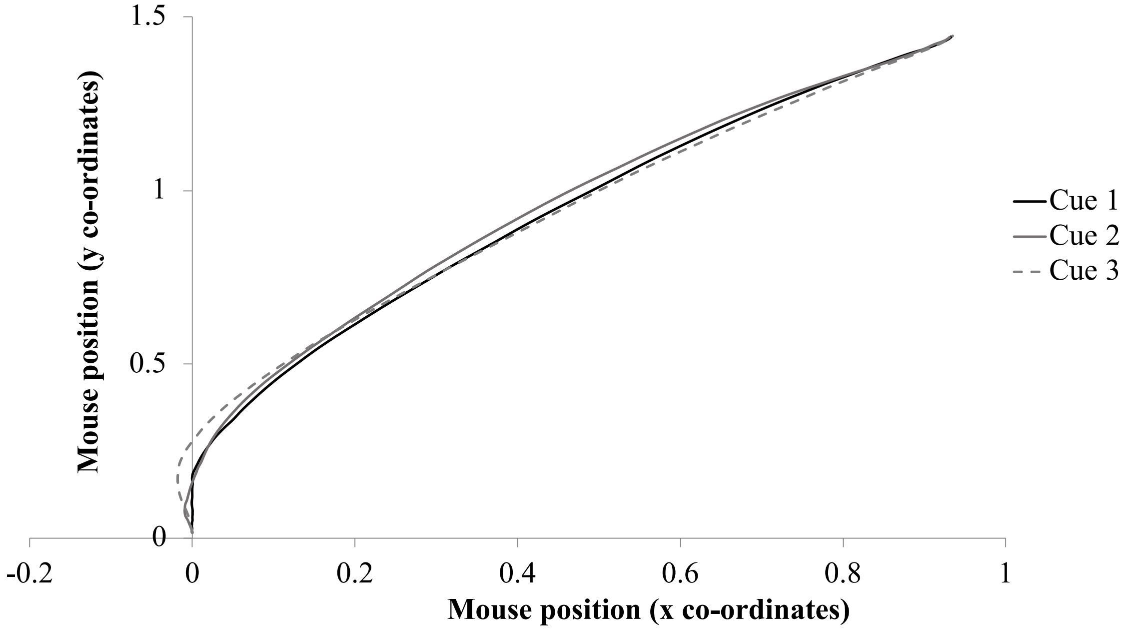
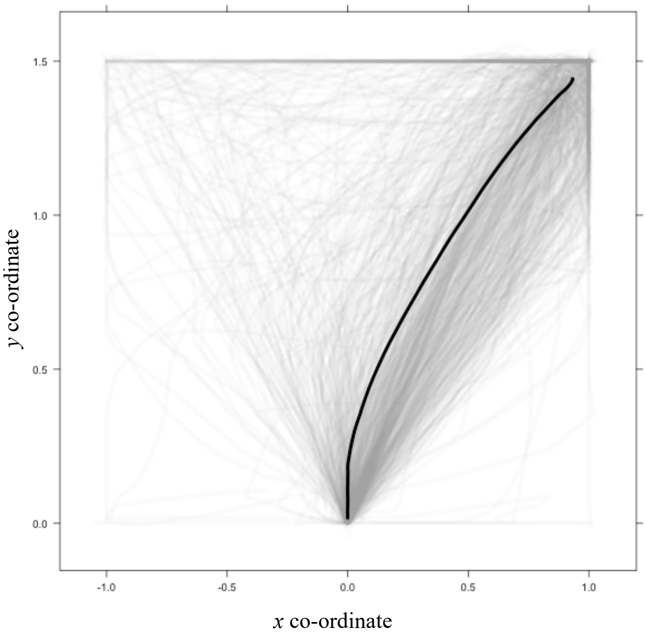
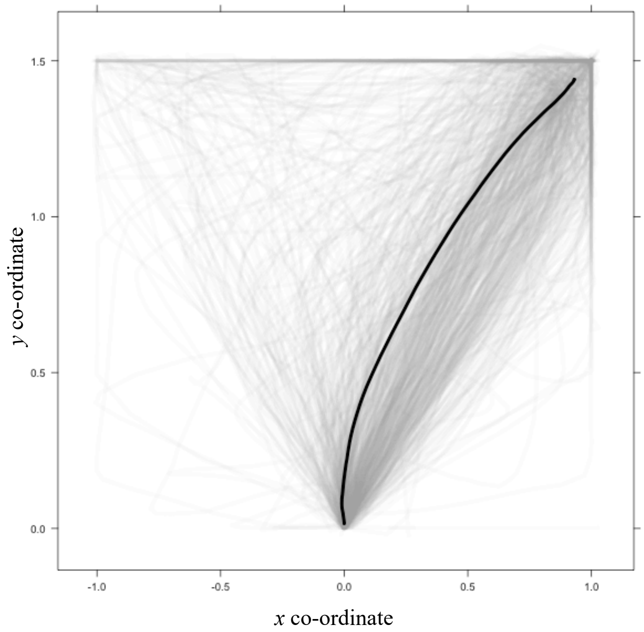


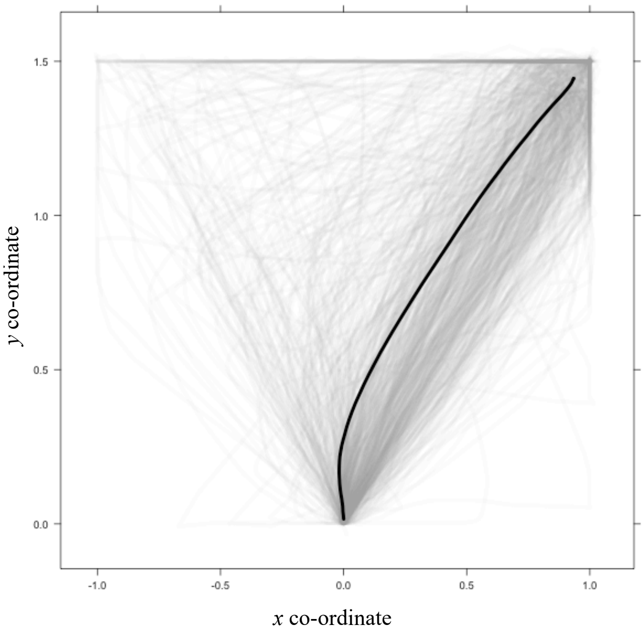
Figure 4.9. The average response trajectory for the three-target condition as the number of cues were increased from one cue to three cues.



(a) One cue



(a) Two cues



(c) Three cues

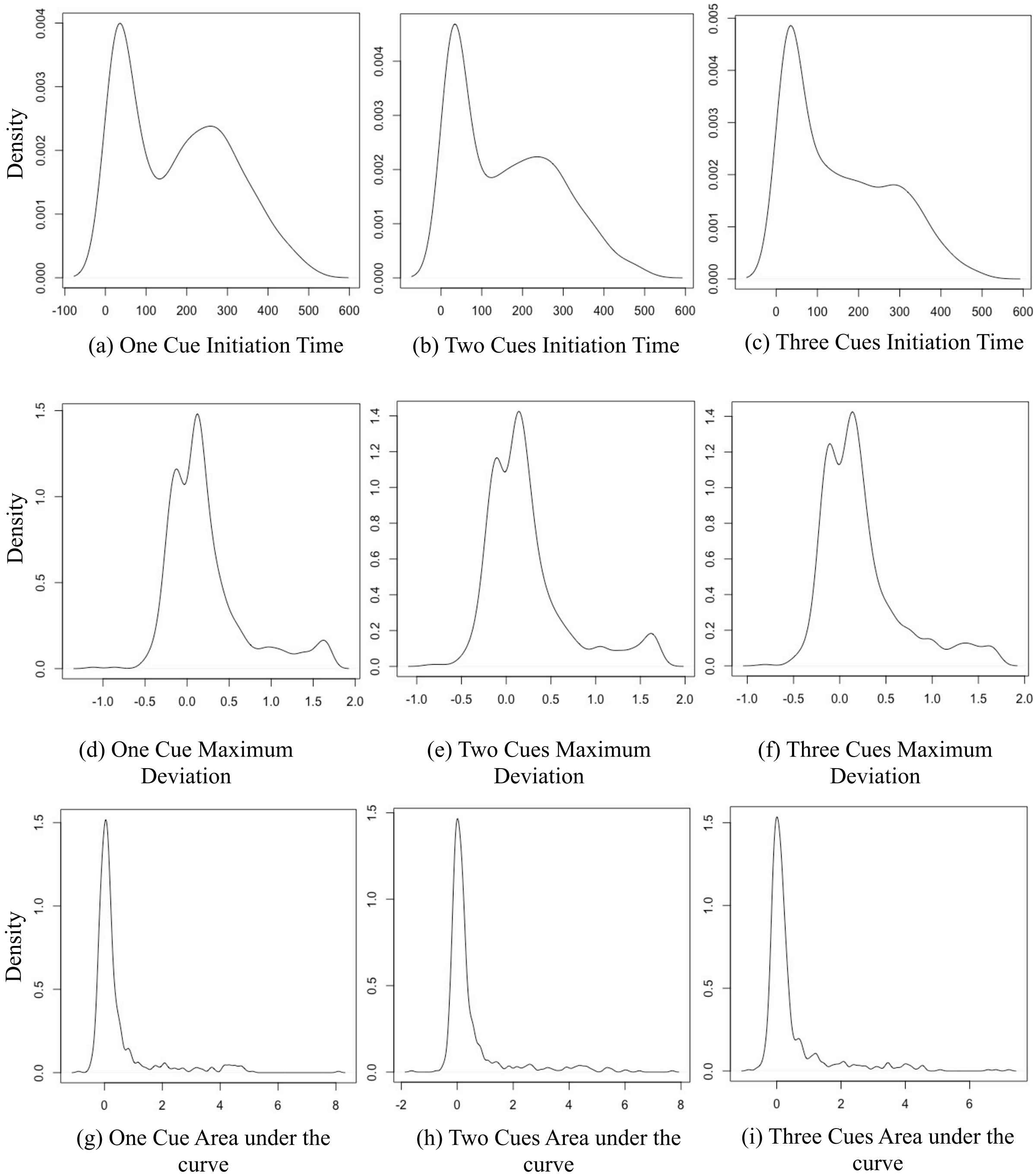
Figure 4.10. All response trajectories from each trial, each line represents a response trajectory from the 'Start' button to response button for (a) One cue, (b) Two cues and (c) Three cues. The heavy black line represents the mean response trajectory. The heavy black line represents the mean response trajectory.

Maximum deviation. Consistent with the response trajectories presented in Figure 4.9 the maximum deviation was similar in all three cue conditions (Table 4.8). A repeated measures ANOVA there was no effect of cues on maximum deviation, $F(2,26) = 0.14$, $p > 0.05$; $\eta p2 = 0.01$.

Area under the curve. As expected from the above findings, a repeated measures ANOVA showed there was no effect of cues on the area under the curve, $F(2,26) = 0.21$, $p > 0.05$; $\eta p2 = 0.02$.

Distributions. As shown Figure 4.10 (a, b, and c) distributions for initiation times were similar in all conditions, where the majority of responses occurred in the first 100 ms and a second peak occurring between 200-350 ms. For initiation time, a bimodal tendency was confirmed in all conditions by Hartigans' dip test in the one cue condition $D = 0.07$, $p < 0.05$, the two-cue condition $D = 0.08$, $p < 0.05$ and the three-cue condition $D = 0.08$, $p < 0.05$. This distribution reflects how participants are encouraged to move the mouse as soon as possible in all conditions and is not driven by the conditions themselves.

Distributions for maximum deviation, also did not differ across conditions. In the left tail, there was evidence of an additional peak (which as stated previously may relate to hand kinematics) and in the right tail, evidence of an additional small peak conditions (Figure 4.10 (d, e, and f). For maximum deviation, Hartigans' dip test confirmed there was a bimodal tendency in all conditions; in the one cue condition $D = 0.07$, $p < 0.05$, the two-cue condition $D = 0.07$, $p < 0.05$ and the three-cue condition $D = 0.06$, $p < 0.05$. This suggests that in all conditions participants responses involved some movement towards the alternative option, however as this appears in all conditions it is not driven by differences in cue conditions. This bimodality is not evident in the distributions for area under the curve, as shown in Figure 4.10 (g, h, and i); distributions are similar in all conditions and peaks initially before distribution rises and dips in the right tail.



(a) One Cue Initiation Time
(b) Two Cues Initiation Time
(c) Three Cues Initiation Time
(d) One Cue Maximum Deviation
(e) Two Cues Maximum Deviation
(f) Three Cues Maximum Deviation
(g) One Cue Area under the curve
(h) Two Cues Area under the curve
(i) Three Cues Area under the curve

Figure 4.11. Distributions across conditions: One cue, Two cues and Three cues for initiation times, maximum deviation and area under the curve.

To conclude, there were no significant differences between the RT's and mouse tracking data suggesting that increasing the number of cues from one to three cues does not have a large impact on participants abilities in target discrimination. Given participants should be moving their mouse as soon as possible and because the average initiation times are fast, it is interesting that cueing appeared to facilitate initial movements as cues increased.

4.7.3 Four-target condition

The following analysis will investigate how increasing the number of cues from one to four cues affects target discrimination in the four-target condition.

Response and initiation times. As shown in Table 4.9, increasing the number of cues from one to four cues resulted in two clusters of RT's, there were similar RT's between one cue and two cues and similar RT's between three cues and four cues. A repeated measures ANOVA demonstrated there was a main effect of cues on the RT's; $F(3,39) = 4.91$, $p < 0.01$; $\eta p2 = 0.27$.

As shown in Table 4.9, a similar pattern also occurred with initiation times and participants were able to start response trajectories faster in the three and four-cues condition. A repeated measures ANOVA demonstrated there was a main effect of cues on initiation times; $F(3,39) = 4.30$, $p < 0.05$; $\eta p2 = 0.25$.

Table 4.9. The Means and Standard Deviation (SD) of Response time (RT), Initiation Time (IT), Maximum Deviation (MD), Area Under the Curve (AUC) and *x*-flips for Four Targets and One, Two, Three and Four Cues

Four Targets

Cues	RT		IT		MD		AUC		*x*-flips	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	893	188	175	81	0.20	0.18	0.40	0.37	6.50	1.76
2	891	194	165	80	0.20	0.20	0.39	0.39	6.44	1.70
3	869	191	157	78	0.13	0.21	0.25	0.25	6.50	1.57
4	874	186	160	77	0.15	0.21	0.30	0.41	6.46	1.49

Response trajectories. Similar to the previous findings, as shown in Figure 4.12, the response trajectories were similar between the one cue and two cues condition, then more direct and similar in the three and four-cues condition. Across all conditions the trajectories take on a similar form and as shown in Figure 4.13, where each individual trajectory has been plotted for each trial in both conditions, there appears to be similarities between all the cue conditions. The differences in RT's and initiation times do not appear to be the result of uncertainty as confirmed by similar average reversals along the x-axis (Table 4.9: *x*-flips). Given no distractors were present this is to be expected. A repeated measures ANOVA showed there was no effect of cues on x-flips; $F(3,39) = 0.08$, $p > 0.05$; $\eta p2 = 0.01$.

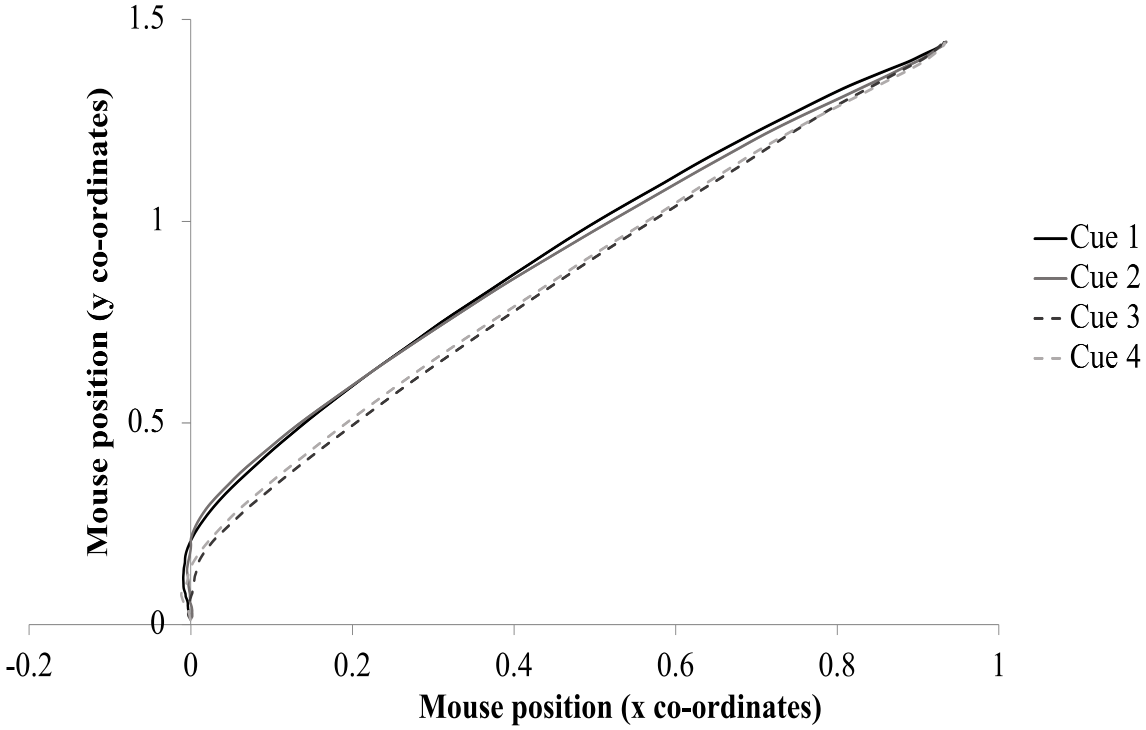
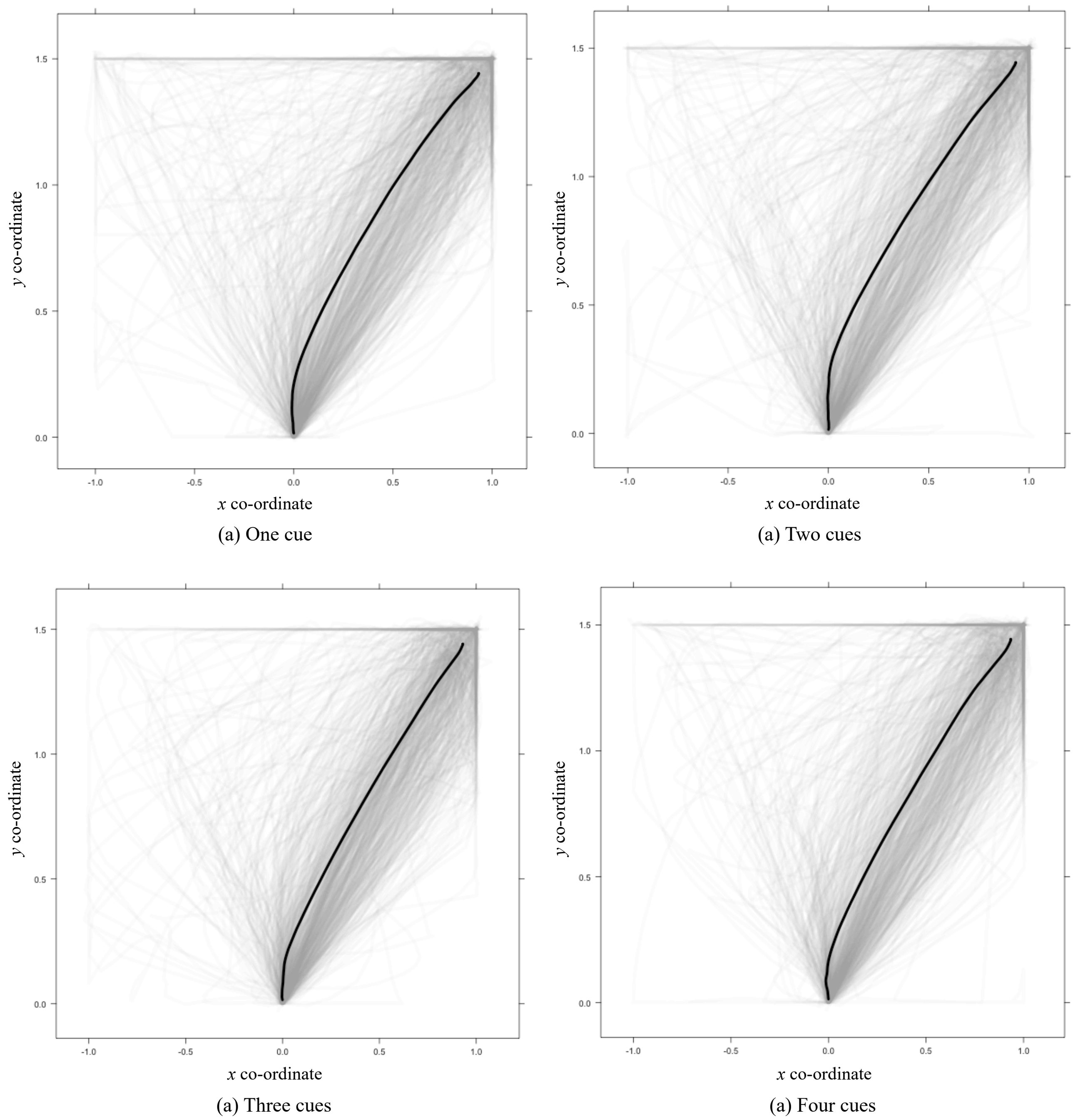


Figure 4.12. The average response trajectory for the four-target condition as the number of cues were increased from one cue to four cues.

Maximum deviation. Consistent with the response trajectories presented in Figure 4.12, there were differences between maximum deviation when one/two cues were present and three/four cues present (Table 4.9). A repeated measures ANOVA confirmed a main effect of cues on the maximum deviation; $F(3,39) = 5.36$, $p < 0.05$; $\eta p2 = 0.29$.

Area under the curve. As expected from the above findings, a repeated measures ANOVA, a main effect of cues on area under the curve; $F(3,39) = 4.67$, $p < 0.05$; $\eta p2 = 0.26$.



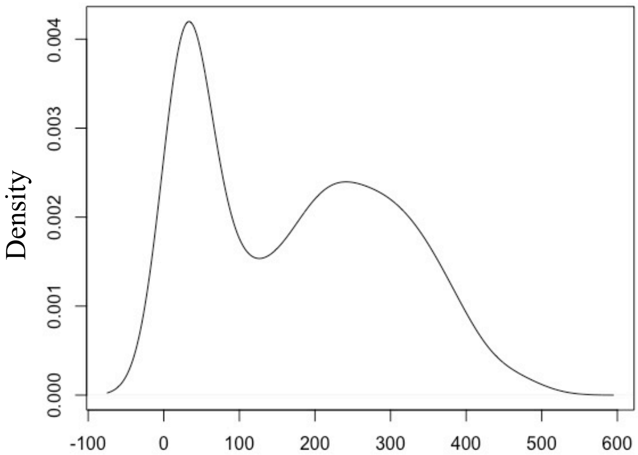
(a) One cue
(a) Two cues
(a) Three cues
(a) Four cues

Figure 4.13. All response trajectories from each trial, each line represents a response trajectory from the 'Start' button to response button for (a) One cue, (b) Two cues, (c) Three cues and (d) Four cues. The heavy black line represents the mean response trajectory.

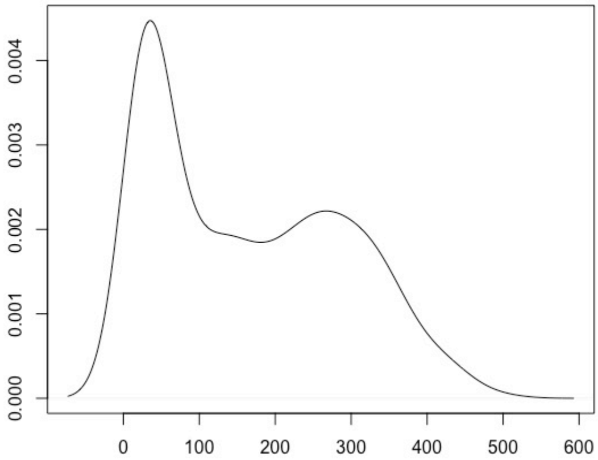
Distributions. As shown Figure 4.14 (a, b, c, and d), distributions for initiation times were similar in all conditions, where the majority of responses occurred in the first 100 ms and a second peak occurring between 300 ms. For initiation time, a bimodal tendency was confirmed in all conditions by Hartigans' dip test in the one cue condition $D = 0.08$, $p < 0.05$, the two-cues condition $D = 0.09$, $p < 0.05$, the three-cues condition $D = 0.09$, $p < 0.05$ and the four-cues condition $D = 0.08$, $p < 0.05$. This distribution reflects how participants are encouraged to move the mouse as soon as possible in all conditions and is not driven by the conditions themselves.

Distributions for maximum deviation, Figure 4.15 (a, b, c, and d), also did not differ across conditions. In the left tail, there was evidence of an additional peak forming (which as stated previously may relate to hand kinematics) and in the right tail a small number of larger maximum deviations which suggests in a small number of trials movements were made towards the incorrect response. Hartigans' dip test stated there was a bimodal tendency in all conditions; in the one cue condition $D = 0.03$, $p < 0.05$, the two-cue condition $D = 0.07$, $p < 0.05$, the three-cues condition $D = 0.04$, $p < 0.05$ and the four-cues condition $D = 0.04$, $p < 0.05$. As this appears across all conditions it does not appear to be driven by the cue conditions themselves. However, this bimodality is not evident in the distributions for area under the curve, as shown in Figure 4.16 (a, b, c, and d); whereby distributions are similar in all conditions and peak initially before distribution fluctuates in the right tail.

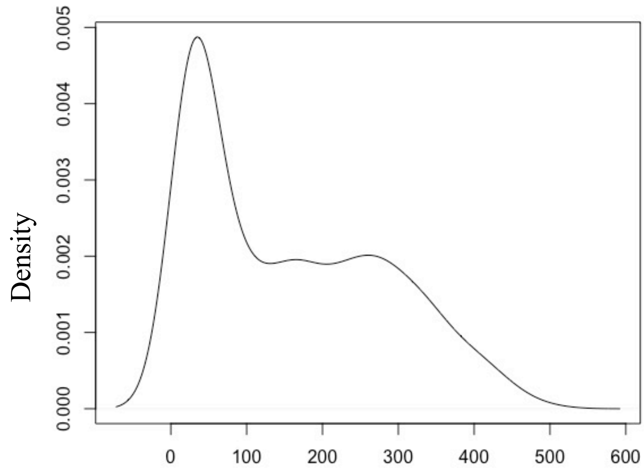
To conclude, the RT's and mouse tracking data suggests that increasing the number of cues from one/two cues to three/four cues impacts a participant's ability to initiate a response which produces significant differences in initiation times, RT's, maximum deviation and area under the curve. The response trajectories demonstrate a similar curve formation for all conditions, but the cues are more direct with three and four cues, this is also reflected in smaller maximum deviations and area under the curve. It is possible that this is due to attention being split across both visual hemifields in all the trials in the three/four cue conditions (although note that some of the two cue conditions will also split attention across both hemifields).



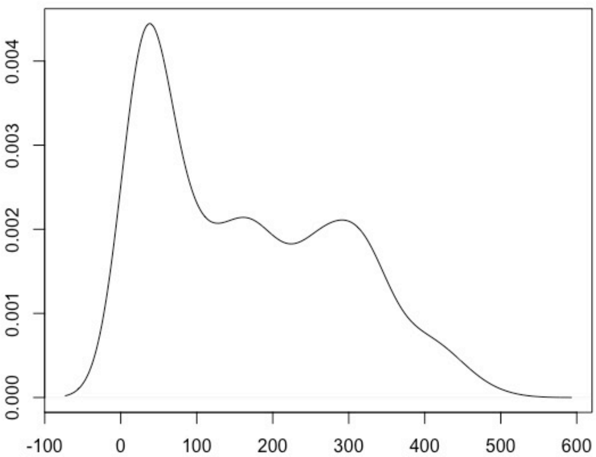
(a) One Cue Initiation Time



(b) Two Cues Initiation Time

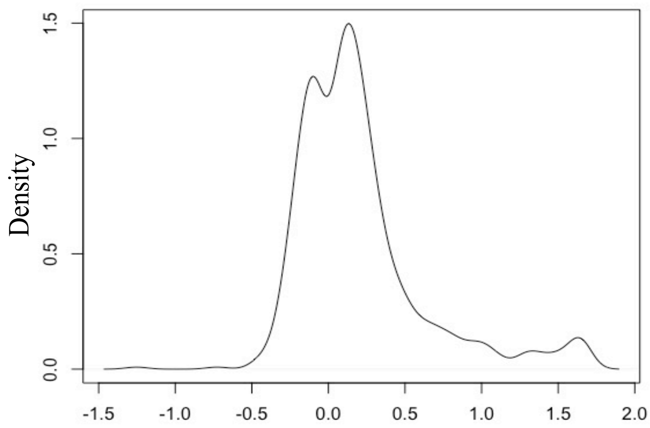


(c) Three Cues Initiation Time

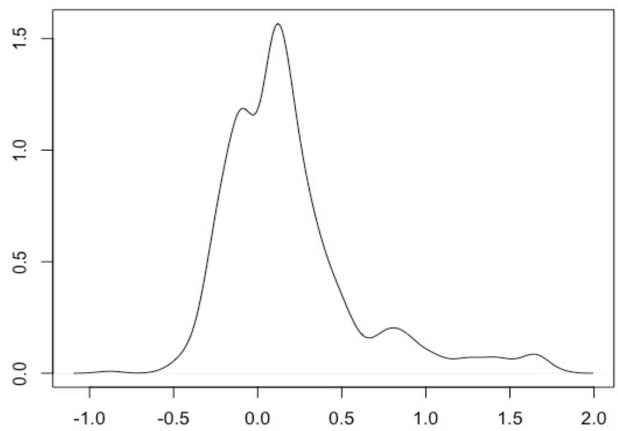


(d) Four Cues Initiation Time

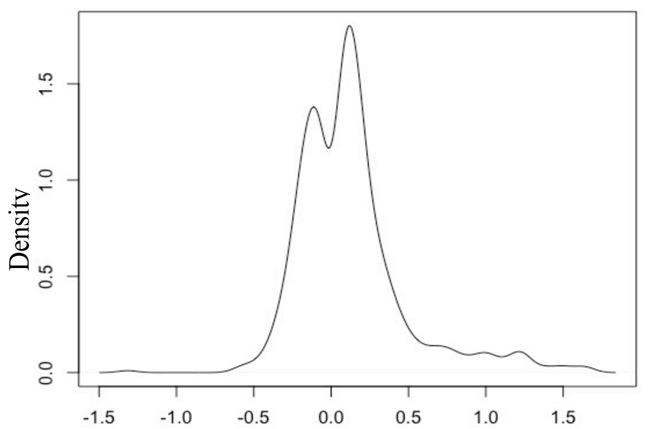
Figure 4.14. Distributions across conditions (a) One cue, (b) Two cues, (c) Three cues and (4) Four cues for initiation times.



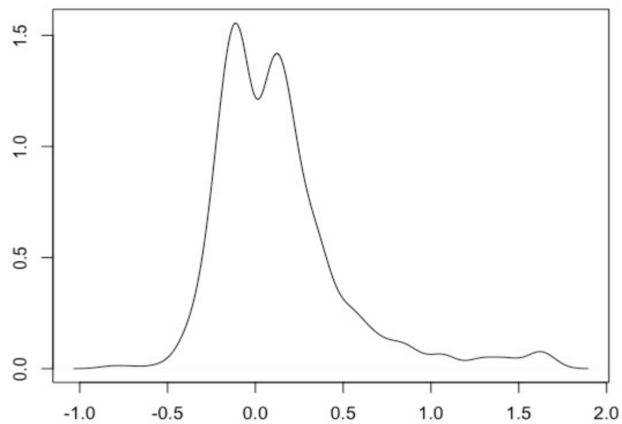
(e) One Cue Maximum deviation



(f) Two Cues Maximum deviation

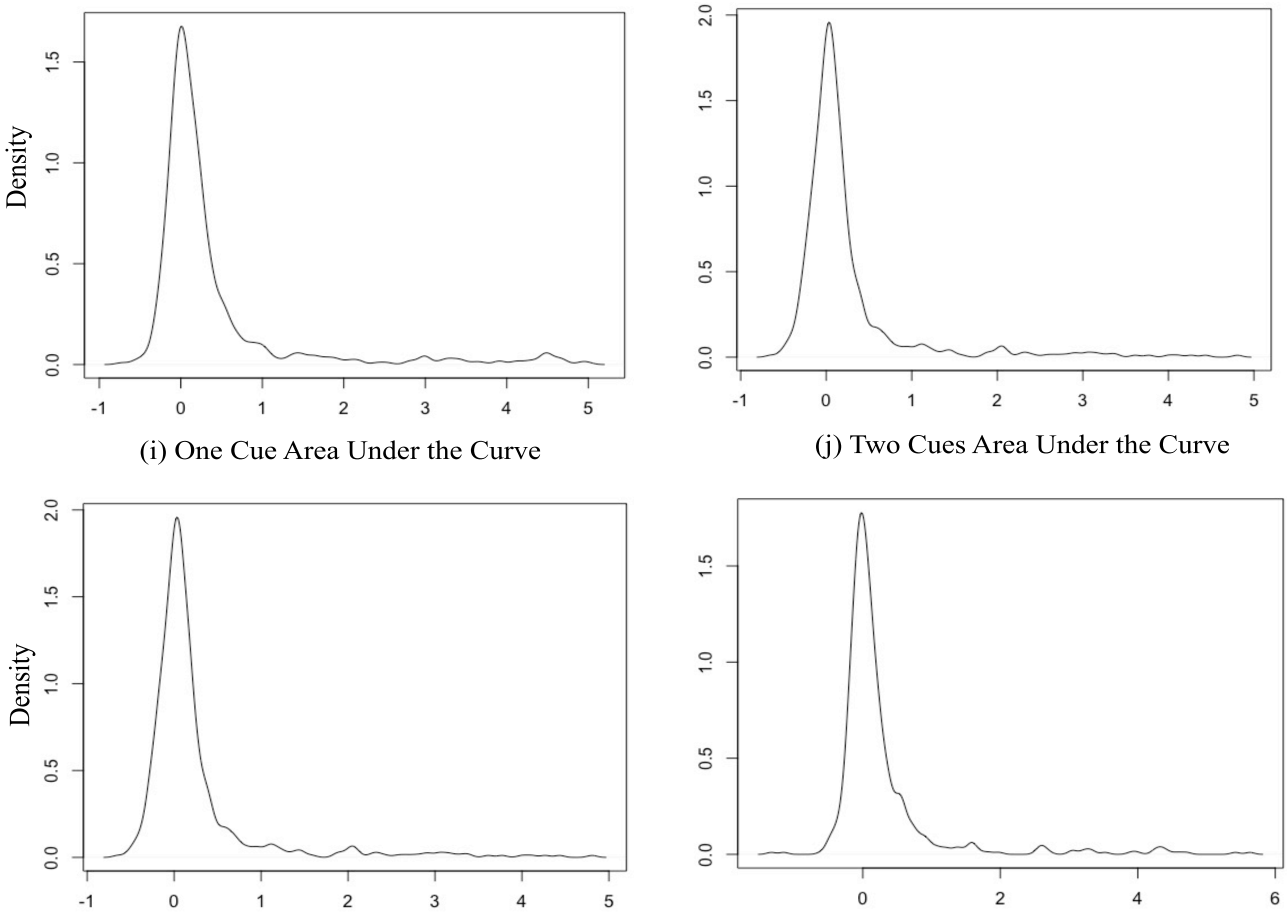


(g) Three Cues Maximum Deviation



(h) Four Cues Maximum Deviation

Figure 4.15. Distributions across conditions (e) One cue, (f) Two cues, (g) Three cues and (h) Four cues for maximum deviation.



(i) One Cue Area Under the Curve

(j) Two Cues Area Under the Curve

(k) Three Cues Area Under the Curve

(l) Four Cues Area Under the Curve

Figure 4.16. Distributions across conditions (i) One cue, (j) Two cues, (k) Three cues and (l) Four cues for area under the curve.

4.8 Data analysis: effect of using informative cues

As shown in the section above, increasing the number of cues in the two and three target conditions did not aid a participant's ability at target discrimination. To further explore if participants are mostly ignoring the cues this analysis will only focus on the effect of using one informative cue versus a non-informative neutral central cue.

Initiation time and response time. As summarised in Table 4.10, initiation times and RT's are faster when a cue is informative compared to a neutral central cue.

In terms of RT's, a repeated measures ANOVA showed no effect of cue conditions, $F(1,13) = 2.12$, $p > 0.05$; $\eta p2 = 0.14$. But consistent with the results above there was an effect of target conditions, $F(3,39) = 37.12$, $p < 0.05$; $\eta p2 = 0.74$ but no cue*target interaction, $F(3,39) = 0.94$ $p > 0.05$, ; $\eta p2 = 0.07$. However, in terms of initiation times a repeated measures ANOVA showed an effect of cue conditions, $F(1,13) = 6.98$, $p < 0.05$; $\eta p2 = 0.35$ and target conditions, $F(3,39) = 3.91$, $p < 0.05$; $\eta p2 = 0.23$. Whilst Kent and Howard (2010) predicted that increasing targets will have more of an impact for the non-informative cue compared to the single informative cue, there was no significant cue*target interaction, $F(3,39) = 0.92$ $p > 0.05$; $\eta p2 = 0.06$.

Table 4.10. Summary of Initiation Times and Response Times Between the Two Cueing Conditions.

	Targets			
	1	2	3	4
Cues				
Initiation time				
Non-informative central cue	200	189	187	183
Informative single cue	184	172	178	175
Response times				
Non-informative central cue	1008	973	926	893
Informative single cue	985	954	922	893

Response trajectories: As shown in Figure 4.17, the average trajectory across all targets, there are small differences in curvature between an informative cue and a non-informative cue at the start of the trajectory although these are inconsistent with differences in initiation times described above where informative cues result in smaller initiation times.

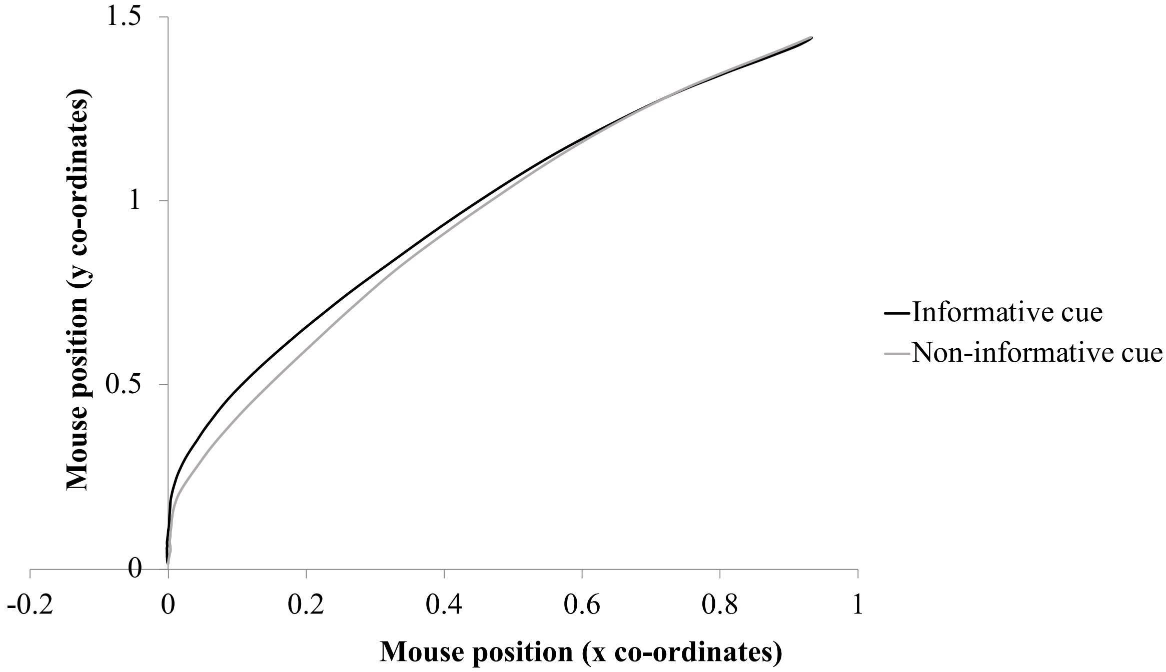


Figure 4.17. Average response trajectories for informative single cue and non-informative central cue for all target conditions.

Maximum deviation and area under the curve. As shown in Table 4.11, maximum deviation was smaller when an informative cue was used except when there was one target. A repeated measures ANOVA showed a main effect between: cue conditions, $F(1,13) = 4.95$, $p < 0.05$; $\eta p2 = 0.28$ and target conditions, $F(3,39) = 20.04$, $p < 0.05$; $\eta p2 = 0.61$ but there was no cue*target interaction, $F(3,39) = 0.46$ $p > 0.05$; $\eta p2 = 0.03$. The area under the curve was also smaller when an informative cue was used except when one target was present. A repeated measures ANOVA showed no main effect of cue conditions, $F(1,13) = 4.61$, $p > 0.05$; $\eta p2 = 0.26$. But there was a main effect between target conditions, $F(3,39) = 17.50$, $p < 0.05$; $\eta p2 = 0.57$ and no cue*target interaction, $F(3,39) = 0.76$ $p > 0.05$; $\eta p2 = 0.05$.

Table 4.11. Summary of Maximum Deviation and Area Under the Curve Between the Two Cueing Conditions.

	Targets			
	1	2	3	4
Cues				
Maximum deviation				
Non-informative central cue	0.33	0.25	0.20	0.15
Informative single cue	0.34	0.29	0.23	0.20
Area under the curve				
Non-informative central cue	0.71	0.51	0.39	0.26
Informative single cue	0.71	0.59	0.48	0.40

To conclude, comparisons between an informative cue versus a non-informative cue shows a more complex picture. Whilst initiation times and RT's were shorter in the informative cue condition, there was only a main effect of cues on initiation times. Response trajectories albeit similar were more direct in the non-informative cue condition. Correspondingly, maximum deviation and area under the curve were smaller in the non-informative cue condition (except when one target was present), and there was only a main effect of cueing on maximum deviation.

4.9 Discussion

The results consistently demonstrate that, as expected, increasing the number of targets and decreasing the number of distractors aids discrimination in visual search tasks. By studying the RT's, initiation times and by providing a trajectory for each response mouse tracking was able to provide strong evidence of increased efficiency at visual search tasks with increased number of targets. This is consistent with the results of the preliminary work of Kent and Howard (2010) who found when using four cues (undiagnostic cue) increasing the number of targets improved target discrimination. Similarly, previous studies have repeatedly demonstrated that increasing the number of distractors has a negative effect on visual search efficiency (Treisman & Gelade, 1980; Wolfe, 1994; McElree and Carrasco, 1999; Carassco and McElree, 2001) and reducing the number of distractors reduces the noise surrounding the target, which aids in finding the target (Sperling & Dosher, 1986). From an information accumulation viewpoint, it would appear that increasing the number of targets simply provides additional information which adds to the evidence of which direction the target is facing. Although this benefit can only occur if attention is not at capacity, and suggests participants were able to attend to the additional information, even when cued to a valid target location.

Whilst a flexible model of attention suggests that increasing set size by adding distractors slows information accumulation because attention is shared between more than one object (Kent, Howard, & Gilchrist, 2012). It is important to note, this was not a strict set size manipulation. In this experiment there were always four items on display and instead the ratio of targets and distractors were manipulated. Therefore, attention had to be split amongst more than one object. From a Similarity Theory viewpoint (Duncan & Humphreys, 1989), it may be that increasing targets aided performance because targets were perceptually grouped as one item. However, in this experiment increasing the target to distractor ratio resulted in a gradual increase in all response dynamics measures. Previous feature search studies using homogenous distractors have not found a gradual attentional cost of adding an additional item (Carrasco et al., 2001, Kent et al., 2012). One explanation proposed is homogenous distractors are grouped perceptually and so there are no additive effects. However, when heterogenous distractors are used Bricolo, Gianesini Fanini, Bundesden and Chelazzi (2002) found gradual differences in processing rates as set sizes increased from 2, 4, 6, and 8 items. In this experiment by using a ratio of distractors and targets there are two types of stimuli, homogenous targets and heterogenous distractors. If, like homogenous distractors, all targets are grouped together and treated as one object increasing the number of targets should not result in a gradual increase in performance. It is possible that the key difference is that heterogenous distractors were also present hence we see gradual differences.

Whilst participants performance was able to improve as targets increased, the same pattern was not found in increasing cues. In the two-target condition, increasing the number of cues did not result in differences in initiation times, RT's or the curvatures of response trajectories. Therefore, it appeared participants did not utilise the cues. Given how consistent the effects of increasing the number of targets was on target discrimination, it is possible that participants chose to focus attention on the targets only and learned to ignore the cues. However, in the three-target condition there were differences in initiation times, this is surprising given participants were asked to move their mouse as soon as possible and initiation times were quick. Nevertheless, increasing the number of cues appeared to have a small effect on how quickly participants were able to initiate their mouse movements.

In the four-target condition, where unlike two-target and three-target conditions no distractors were present, increasing the number of cues from one/two to three/four not only decreased initiation times but also improved search efficiency in terms of RT's and the curvatures of the response trajectories. This is consistent with previous research which has found that increasing covert attention with the inclusion of cues can aid discrimination by reducing uncertainty, helping to filter irrelevant information and accelerating processing speeds (Prinzmetal et al., 1998; Lu et al., 2002; Carrasco & Yeshurun 1998; Carrasco & McElree, 2001). There were few differences between one/two cues and three/four cues, the differences only arose when two cues increased to three or more cues. It is useful to note that this benefit may not have appeared so strongly in the previous three-target condition because distractors were present. This advantage of using three/four cues may simply be because the extra cues provided additional information which participants were unable to ignore however, the pattern of results is not consistent with the gradual benefit of attention found in increasing targets/decreasing distractors. As mentioned earlier, it is also possible these results are due to three/four cues involving more trials that involve both visual hemifields (Discussed further in Chapter 5).

These results also contradict the preliminary research from Kent and Howard (2010), who demonstrated participants did not have capacity to attend to more than one cue. Although these differences may be explained through differences in methodology, as preliminary research it was based on the data from five participants and the design also differed considerably, when cues were manipulated participants were always presented with four targets and no distractors were present.

Finally, the preliminary results from Kent and Howard (2010) would suggest that having an informative cue should make visual search tasks significantly more efficient than having a non-informative cue. However, the results presented above demonstrate that largely there was no effect of increasing the number of cues. To investigate whether participants were ignoring cues, in the final analysis, a single informative cue was compared with a central cue.

The results demonstrated that whilst an informative cue had a significant impact on initiation times there was no significant difference between cue conditions for RT's. Therefore, it would appear with an informative cue the mouse is initially moved quicker but overall this has no impact on RT's. Contrary to the initiation time findings, response trajectories whilst similar for both cue conditions were slightly more direct in the non-informative cue. The maximum deviation and area under the curve were also smaller when a non-informative cue was used. The mouse tracking findings support the notion that cues were largely ignored by participants. It is possible due to the large number of conditions and trials the participants took part in, participants simply developed a strategy to ignore cues and utilise the number of targets presented instead.

The preliminary results from Kent and Howard (2010) also demonstrated that increasing targets should have a larger impact for the non-informative cue compared to the single cue. However, there were no interactions between targets and cues in any mouse tracking measurement. Although the results from Kent and Howard (2010) compared a single informative cue with a non-informative cue whereby all four potential locations were cued. Therefore, a direct comparison may not be applicable.

Overall, this study demonstrates that mouse tracking was able to provide useful evidence of efficiency and attentional capacity in visual search tasks. In terms of increasing the number of targets and decreasing distractors the analysis of response trajectories was able to consistently demonstrate that participants were better able to discriminate target orientation. The analysis of x-flips also demonstrated that participants were less likely to move towards the incorrect response before choosing the correct response with increased number of targets. In terms of increasing the number of cues, whilst RT's did not significantly differ in the three-target conditions, mouse tracking analysis was able to indicate that increasing the cues was impacting participants responses as initiation times were faster and differences in response trajectories were beginning to form. A pattern which was then continued in the target four condition where there were differences between one/two cues and three/four cues.

Chapter 5 Hemifield effects in visual discrimination tasks

5.1 Chapter summary

This chapter will investigate whether presenting cues or targets on the same or different sides of the visual field affected visual search efficiency. Previous research has indicated that attention may be allocated separately to different visual hemifields (Alvarez & Cavanagh, 2005). Specifically, Reardon, Kelly and Matthews (2009) found that participants were able to detect a target and discriminate its orientation more efficiently when targets were presented in different hemifields, but only when distractors were present. A reanalysis of Experiment 4 found presenting targets with distractors demonstrated no hemifield effects. An additional experiment, run without distractors, found there were no differences between RT's and initiation times however, the mouse tracking analysis was able to demonstrate a hemifield advantage for bilateral stimuli.

5.2 Introduction

The visual field is divided into two hemifields, visual information from the left visual field is processed by the visual cortex in the right hemisphere of the brain and visual information from the right visual field is processed by the visual cortex in the left hemisphere of the brain. Stimuli presented in one visual field is known as unilateral and stimuli presented across both hemifields is known as bilateral. The results from Chapter 4 demonstrated differences in mouse tracking trajectories between one/two cues and three/four cues, one potential reason for this increase is that in the later condition more cues were presented across both hemifields.

Alvarez and Cavanagh (2005) demonstrated that attention could operate independently in each hemifield, and thus when targets were split between two hemifields (bilateral) twice as many targets could be identified. Using two rotating sinusoidal gratings (rotating disks), participants were either asked to track one probe bar in one sinusoidal grating or one probe bar in both sinusoidal gratings (Figure 5.1). In bilateral trials, stimuli were presented above or below the fixation point. In unilateral trials, stimuli were presented on either side of the fixation point. At the start of each trial, the target location was indicated for two seconds, before rotations began for three seconds. Once rotations were complete a line indicated one probe bar. Participants were asked to identify if this was the same probe bar that had been originally indicated by responding yes or no. When one target was presented, participants' accuracy was similar across both conditions. However, when two targets were used participants accuracy dropped significantly when they were presented in the same unilateral visual field (Figure 5.1). The authors concluded that these results were consistent with the concept that each hemifield has its own independent resource which is shared within a hemifield.

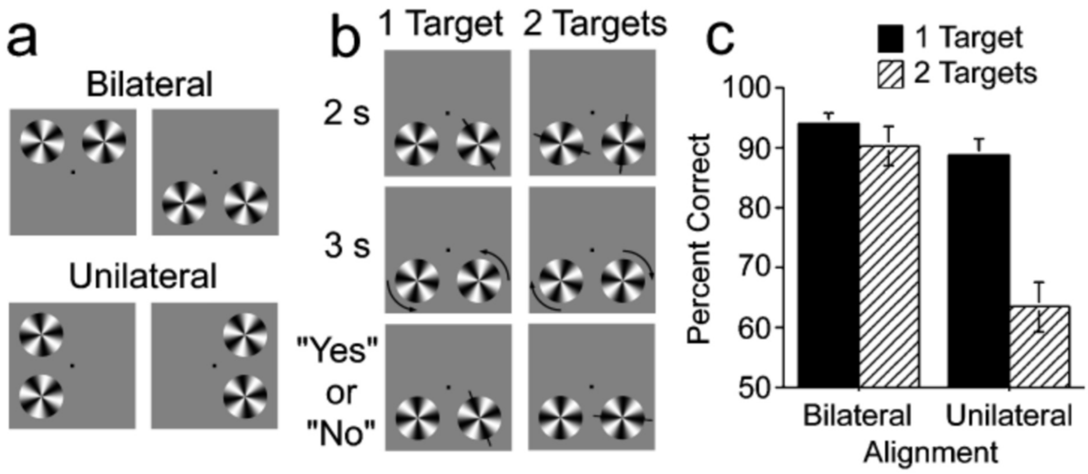


Figure 5.1. Example trial sequences and results from the first hemifield experiment run by Alvarez & Cavanagh (2005) investigation, taken from Alvarez, G. A., & Cavanagh, P. (2005). Independent resources for attentional tracking in the left and right visual hemifields. *Psychological Science*, *16*, 638.

Reardon, Kelly and Matthews (2009) ran a series of experiments to investigate whether a bilateral advantage could also impact low-level tasks such as target discrimination and target detection in visual search tasks. In the first experiment participants were asked to complete an orientation discrimination tasks and identify whether two Gabor patches were the same or different. Targets were either displayed at the top or bottom quadrants of the screen (bilateral) or in the right or left quadrants (unilateral). Before each target appeared a pair of peripheral cues and a computerised voiced indicated whether the targets would appear at the top, bottom, left or right-hand side of the screen. The two stimuli either appeared on their own or with two distractors which either differed by orientated or spatial frequency. The results demonstrated that only when distractors were present, presenting targets bilaterally resulted in greater orientation sensitivity than targets which were presented unilaterally. The authors suggest that the increased attentional demand of requiring distractors to be excluded means that neural activity has to cross the corpus callosum, so it is beneficial for the task to occur between hemifields.

In a second experiment, Reardon et al. (2009) used a target detection task to explore how participants used redundant information whereby the number of targets were manipulated. A comparison was made between one target, where there was no redundant information and two targets where one of the two targets provided redundant information. Bilateral and unilateral conditions were determined by whether the peripheral cues, which appeared before the targets, were bilateral or unilateral. As in the previous experiment, targets either appeared with distractors or without distractors. The results replicated the previous findings that bilateral effects were only identifiable with the presence of distractors. Similar to Experiment 4, the authors found that increasing the number of targets from one to two resulted in significantly better detection rates.

Given the design of the previous experiment, whereby targets and cues were presented in a grid formation, it was possible to focus on whether targets and cues presented bilaterally or unilaterally aided target discrimination (Figure 5.2).

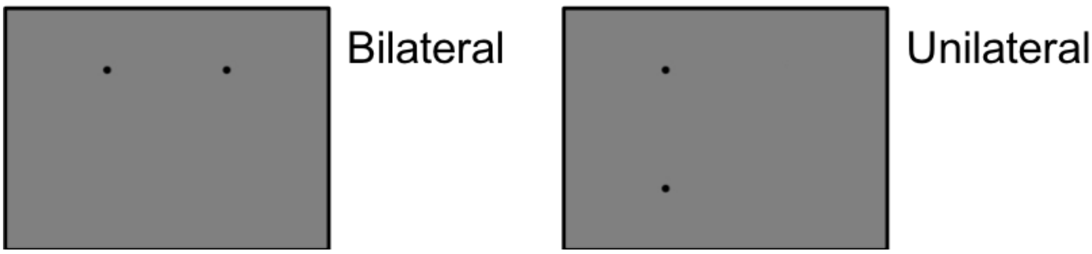


Figure 5.2. Example of bilateral and unilateral placement of cues and targets from Experiment 4.

An initial review of the results from the previous experiment demonstrates that in the neutral cue condition with two targets presenting targets bilaterally across all cues results in lower RT's (M = 946, SD = 191) compared with when targets were presented unilaterally (M = 991, SD = 181). Although this was not a significant result; 95% CI [-90.99 to 0.46], $t(13) = 2.14$, p >0.05, the differences were close to significant (p = 0.052) and in the direction expected; therefore it seems further exploration would be worthwhile. Similarly, there was an advantage to RT's when cues were presented bilaterally to two targets (M = 943, SD = 197) compared when cues were presented unilaterally (M = 953, SD = 220). Although again this failed to reach threshold for significance; 95% CI [-72.46 to 51.12], $t(13) = 0.37$, p >0.05, the RT's were reduced in the direction expected, and further exploration could be worthwhile. In order to replicate the finding of Reardon et al. (2009) and explore whether a bilateral hemifield advantage was present with distractors it will be necessary to undertake a detailed analysis of the two-cue condition with two targets (removing all diagonal cues and targets).

In order to demonstrate that the hemifield advantage is not present when distractors are absent, an additional experiment was run without distractors. By comparing the results from Experiment 4 with the results from Experiment 5, it is possible to explore the effect of distractors on any hemifield advantages. According to the results of Reardon et al. (2009), it is expected there will be significant bilateral effects when distractors are present but not when they are absent. In terms of the mouse tracking data, we would expect the results from Experiment 4, to result in shorter RT's, error rates and direct response trajectories with corresponding smaller maximum deviations and areas under the curve. However, we would not expect differences to see these differences in Experiment 5 when distractors are not present.

5.3 Methods

Participants. Twenty-two undergraduate students (13 female) aged between 18 and 28 took part in the experiment. All participants had normal or corrected-to normal vision.

Materials and stimuli. Using the same materials as Experiment 4, stimuli were displayed on a 15.4-inch laptop screen with resolution of 1,280 x 800 pixel and 60Hz refresh rate. The stimuli were presented in a darkened room. Participants sat approximately 50 cm from the screen and had to move a cordless mouse placed on the right-hand side of the laptop to respond.

Using the exact same stimuli as Experiment 4, each stimulus consisted of Gabor patches (suprathreshold sinusoidal gratings vignette by a Gaussian envelope) that varied on two dimensions, orientation and spatial frequency. The target was a 2 cycle per degree (cpd) Gabor target which was tilted to the right or left. The distractors were either an 8 cpd Gabor patch (spatial frequency) tilted to the same degree or a vertical 2 cpd Gabor patch (orientation). A cue consisted of a black circle (20 px x 20 px) which appeared at the same location as the targets (50 px x 50 px). For each trial, stimuli were presented at two out of a potential four locations equidistance from the centre of the screen (co-ordinates 320 px, 200 px; co-ordinates 320 px, 600 px; co-ordinates 960 px, 200 px and co-ordinates 960 px, 600 px).

The MouseTracker space represents a 2 x 1.5 rectangle, the start button and start of all response trajectories is located in the bottom centre of the screen (co-ordinates 640 px, 0 px). One response button located in at the top hand side of the screen (co-ordinates 0 px, 800 px) and the other response button is located at the top right-hand side of the screen (co-ordinates 1024 px, 1280 px).

Procedure. The procedure was identical to Experiment 4, except participants were only presented with two targets and two valid cues to indicate the location of the target.

Design. Targets were either presented bilaterally or unilaterally with two targets being presented at two of the four locations equidistant from a central fixation point (Figure 5.2). The corresponding cues were either bilateral or unilateral. Participants took part in a total of 480 trials, the target was presented 60 times in each condition and whether the target was orientated to the left or right was counterbalanced.

Exclusion criteria. Using the same criteria as Experiment 4, trials initiated later than 500 ms and response time longer than 2,000 ms as well as trials where participants failed to respond or gave an incorrect response; resulted in a total 2.9% of trials were excluded.

Due to a change in experimenters and incorrect instructions being given this resulted in 6 participants being removed as over 49% of their trials were incorrect. This left 16 participants remaining. Once removed this resulted in average error rates of 6% in the bilateral condition and 6% in the unilateral condition.

By focusing on when bilateral and unilateral cues were used with corresponding bilateral targets and unilateral targets from the analysis in the previous experiment where distractors were present (Experiment 4), and the data from the additional experiment, where distractors were not present (Experiment 5), it is possible to explore the effect of distractors on a hemifield advantage.

5.4 Reanalysis of mouse tracking data from Experiment 4 (distractors present) and analysis of data from Experiment 5 (distractors absent)

Response and initiation times: Table 5.1 shows that when distractors were present (Experiment 4) the bilateral cues resulted in the shortest RT's compared to a unilateral cue. As one experiment involved the reanalysis of existing data (413 trials) and the second set of data came from a separate experiment (1906 trials) there were large differences in the number of trials. Rather than running a mixed effects ANOVA to compare bilateral and unilateral cues when distractors were absent and present, a paired samples t-test comparing the two different type of cues in each experiment was conducted. A paired samples t-test comparing the bilateral cue with the unilateral cue showed this was not significantly different, 95% CI [-72.46 to 51.12], $t(13) = -0.37$, $p > 0.05$; $d = 0.10$. When distractors were absent, the bilateral cue resulted in the shortest RT's compared to a unilateral cue. A paired samples t-test comparing the bilateral cue with the unilateral cues demonstrated they were not significantly different, 95% CI [-20.18 to 5.91], $t(15) = -1.16$, $p > 0.05$; $d = 0.61$

As shown in Table 5.1, when distractors were present, initiation times with a bilateral cue was almost identical to a unilateral cue a paired samples t-test demonstrated this was not significantly different, 95% CI [-17.58 to 18.61], $t(13) = 0.06$, $p > 0.05$, $d = 0.02$. When distractors were absent (Experiment 5), initiation times with a bilateral cue was almost identical to a unilateral cue. The difference between the bilateral cue and the unilateral cue was not significantly different, 95% CI [-6.60 to 10.67], $t(15) = 0.50$, $p < 0.05$; $d = 0.13$.

Table 5.1. Means and Standard Deviations of Initiation Times (IT) and Response Times (RT) When Cues and Targets Were Presented Bilaterally and Unilaterally

Distractors:	**Present**		**Absent**		**Present**		**Absent**	
	IT				RT			
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Bilateral stimuli	168	87	179	64	943	197	907	139
Unilateral stimuli	167	87	177	63	953	220	914	141

Response trajectories. When distractors are present, the initiation time and response time data from Experiment 4 do not demonstrate differences between bilateral and unilateral cues. However, by using mouse tracking it is possible to explore potential differences in participants response trajectories. Average response trajectories (Figure 5.3) demonstrate that bilateral cues initially result in a more direct trajectory and unilaterally cues are more advantageous later on in a trial; although these differences are not large. Figure 5.4 demonstrates that there is similar activity in both conditions although there are marginally more trajectories made near the incorrect response box for the unilateral condition.

When distractors are absent Figure 5.3 demonstrates that when distractors were absent the response trajectory was more direct for bilateral cues compared to unilateral cues. This is also shown in the response trajectories plots in Figure 5.4, where there is more activity in the upper left quadrant for unilateral stimuli compared with bilateral stimuli. This suggests that with unilateral cues and targets participants demonstrated more uncertainty and were attracted to the alternative option before choosing the correct option. Unlike Reardon et al. (2009) and Experiment 4 with distractors there appears to be a bilateral advantage when distractors were not present.

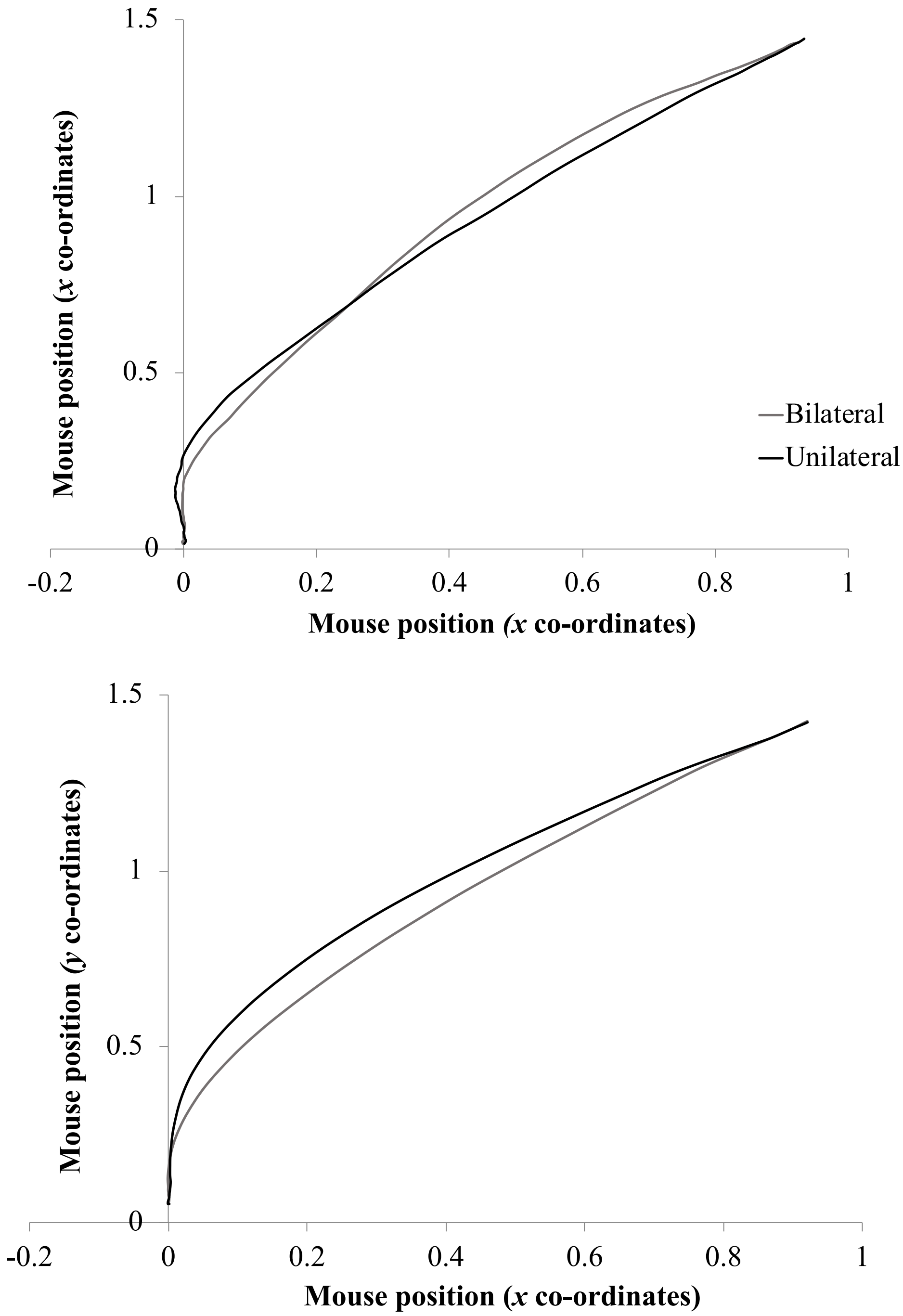


Figure 5.3. Response trajectories for bilateral and unilateral stimuli when (a) Distractors were present (Experiment 4) and (b) Distractors were absent (Experiment 5).

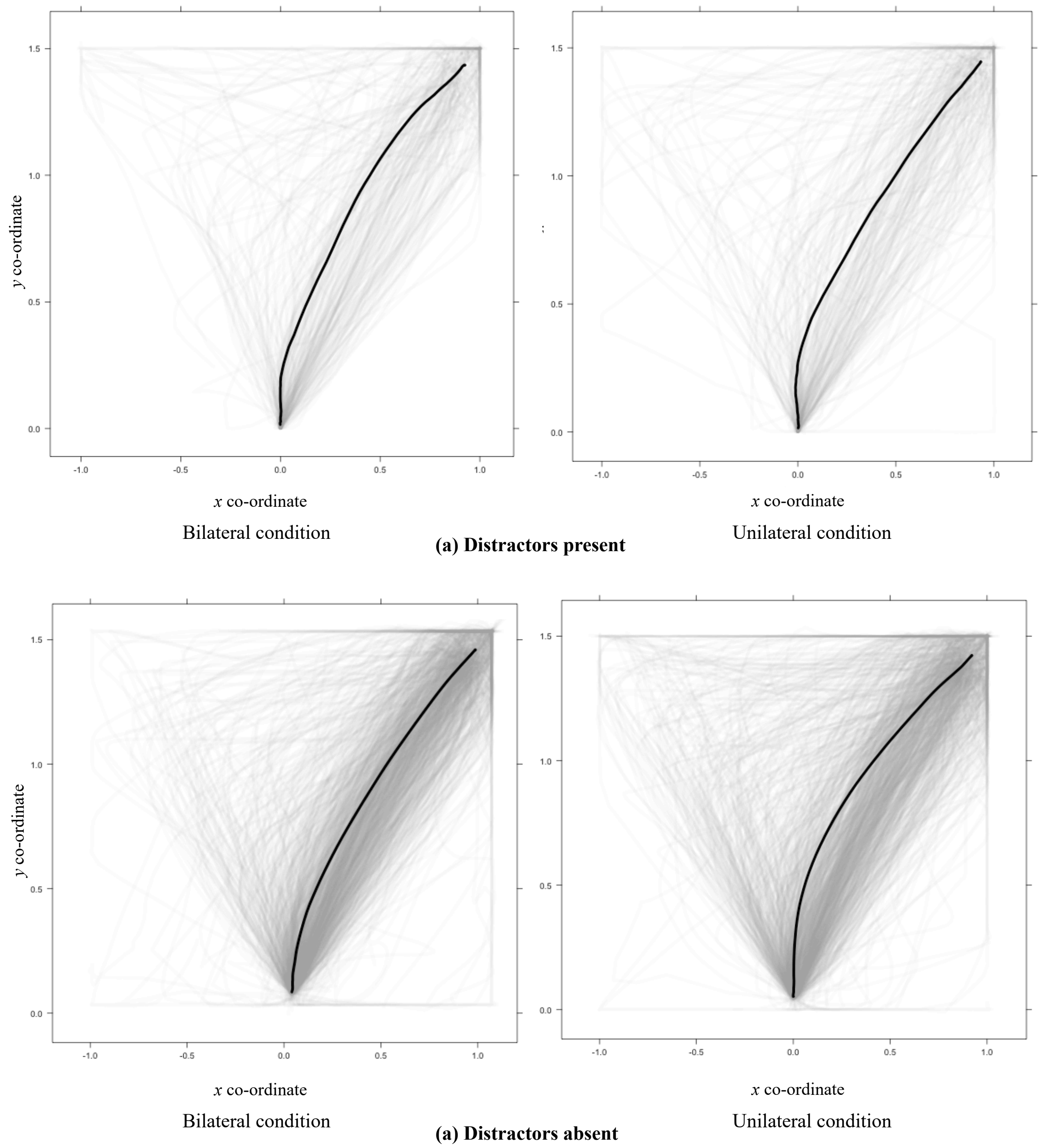


Figure 5.4. All response trajectories for a trial, each line represents a response trajectory from the 'Start' button to response button for two bilateral cues and two bilateral targets and two unilateral cues and two unilateral targets when: (a) when distractors were present (b) when distractors were absent. The heavy black line represents the mean response trajectory in each condition.

Maximum deviation and area under the curve. Table 5.2 shows that when distractors were present (Experiment 4), bilateral cues resulted in slightly smaller maximum deviations compared to unilateral cues. A paired samples t-test demonstrated the difference was not significant between bilateral cues and unilateral cues; 95% CI [-0.11 to 0.08]; $t(13) = -0.26$, $p>0.05$, d=0.07. As Table 5.2 demonstrates when distractors were absent (Experiment 5), in terms of maximum deviation, the bilateral cue resulted in a smaller maximum deviation compared to a unilateral cue. A paired samples t-test demonstrated that there was a hemifield advantage for maximum deviation of presenting the cues bilaterally as shown by a significant difference between bilateral cues and unilateral cues; 95% CI [-0.15 to -0.05]; $t(15) = -4.38$, $p<0.01$, $d = 1.09$.

Table 5.2 below shows that when distractors were present (Experiment 4), bilateral cues resulted in slightly smaller areas under the curve compared to unilateral cues. A paired samples t-test demonstrated the difference was not significant between bilateral cues and unilateral cues; 95% CI [-0.28 to -0.19]; $t(13) = -0.41$, $p > 0.05$, $d = 0.11$. As Table 5.2 demonstrates when distractors were absent (Experiment 5) the area under the curve was smallest with a bilateral cue, compared to a unilateral cue. A paired samples t-test demonstrated that there was a significant hemifield advantage of presenting bilateral cues compared to unilateral cues; 95% CI [-0.29 to -0.11]; $t(15) = -4.65$, $p < 0.01$, $d = 1.17$.

Table 5.2. Maximum Deviation (MD) and Area Under the Curve (AUC) When Cues and Targets Were Presented Bilaterally and Unilaterally

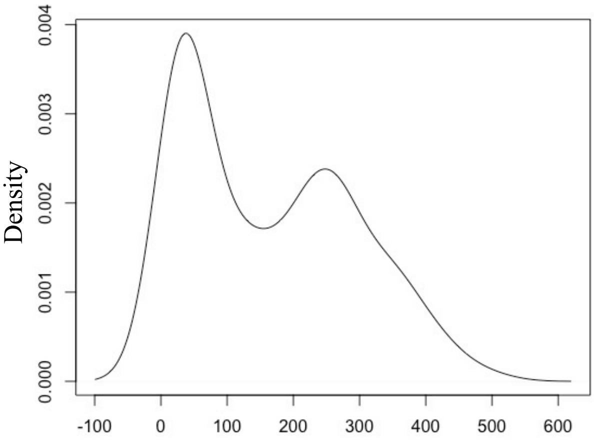
Distractors:	**Present**		**Absent**		**Present**		**Absent**	
	MD				AUC			
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Bilateral stimuli	0.24	0.23	0.18	0.08	0.49	0.45	0.29	0.16
Unilateral stimuli	0.26	0.20	0.28	0.11	0.53	0.51	0.49	0.22

Distributions. Overall the density plots for initiation time, area under the curve and maximum deviation demonstrate no large differences between bilateral and unilateral condition when distractors were present (Figure 5.5) or when distractors were absent (Figure 5.6).

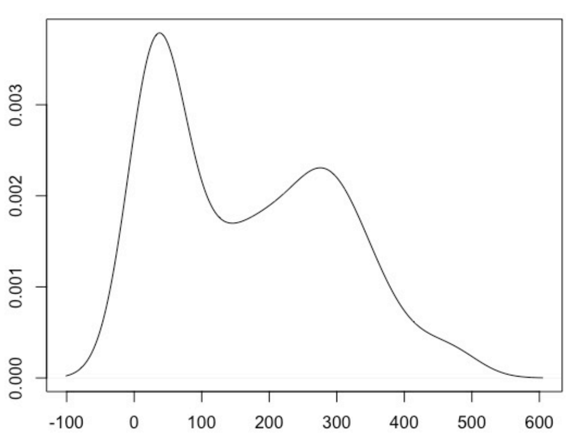
As shown in Figure 5.5, when distractors were present for each condition participants initiation times demonstrated a bimodal tendency in each condition. This was confirmed by Hartigans' dip test, for the bilateral condition, D =0.07, $p < 0.01$ and for the unilateral condition D =0.09, $p < 0.01$. As shown in the density plots in Figure 5.6, when distractors were absent participants also demonstrated a bimodal tendency in each condition. This was also confirmed by Hartigans' dip test, for the bilateral condition, D =0.08, $p < 0.01$ and for the unilateral condition $D = 0.07$, $p < 0.01$. As mentioned in previous chapters, bimodality in initiation times could simply reflect the design of the MouseTracker software, given this appears across all conditions it is therefore unlikely to be driven by the conditions themselves.

Distributions for maximum deviation when distractors were present (Figure 5.5) suggests participants demonstrate a number of larger maximum deviations in the right tail which indicate in a small number of trials mid-flight corrections occurred. Hartigans' dip test confirmed bimodality in both the bilateral condition, $D = 0.04$, $p < 0.01$ and the unilateral condition $D = 0.05$, $p < 0.01$. Figure 5.6 demonstrates that when distractors were absent there was a small number of larger maximum deviations in the right tail of the unilateral condition. In the left tail, there was evidence of an additional peak forming (which as stated previously may relate to hand kinematics). Hartigans dip test confirmed bimodality in both the bilateral condition, $D = 0.04$, $p < 0.01$ and for the unilateral condition $D = 0.05$, $p < 0.01$.

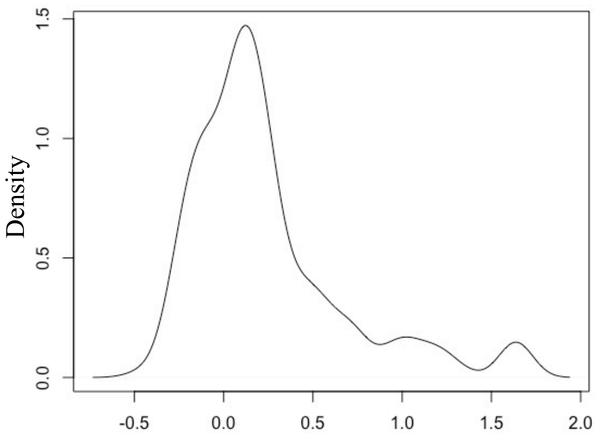
Figure 5.5 and 5.6 demonstrates that no bimodality was present for area under the curve in either the bilateral or unilateral condition.



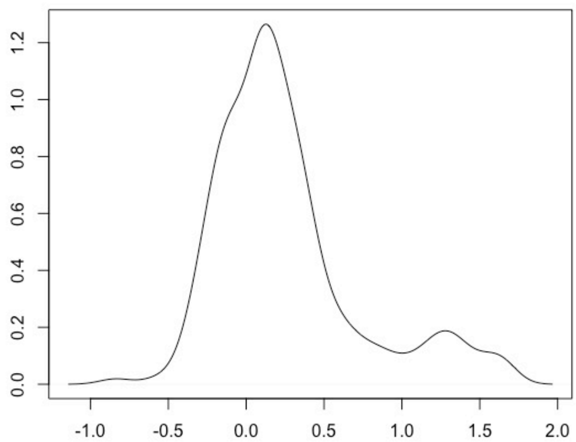
(a) Bilateral Initiation Time



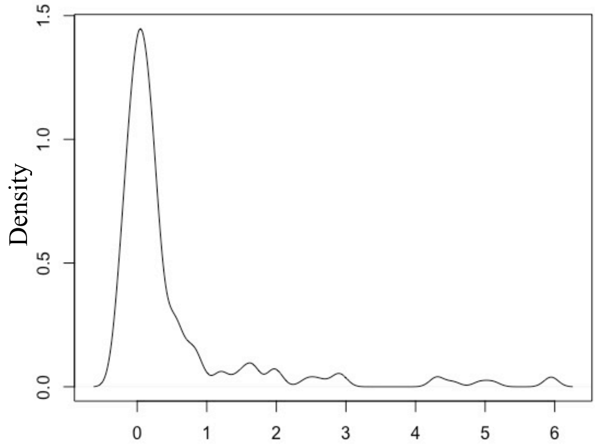
(b) Unilateral Initiation Time



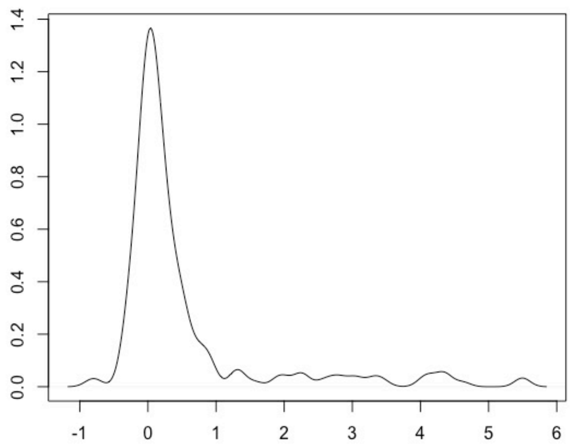
(e) Bilateral Maximum Deviation



(f) Unilateral Maximum Deviation

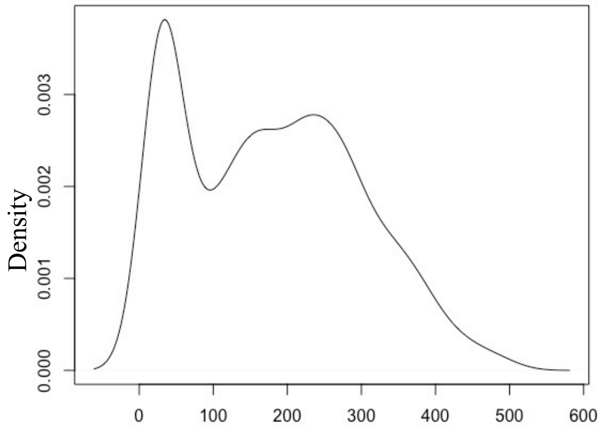


(g) Bilateral Area under the curve

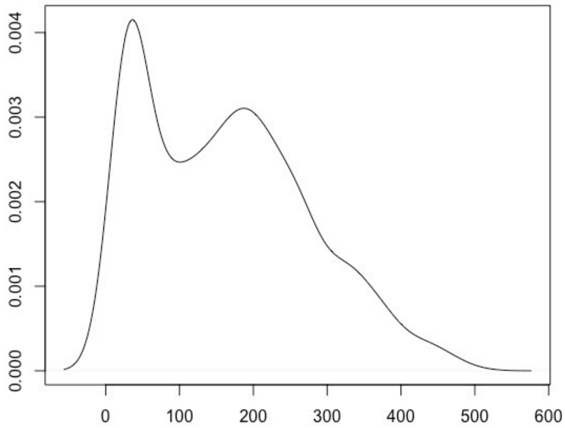


(h) Unilateral Area under the curve

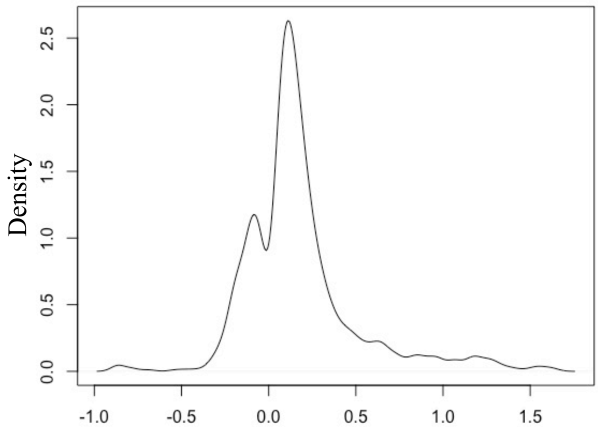
Figure 5.5. Distributions across bilateral and unilateral conditions for initiation times, response times, maximum deviation and area under the curve, when distractors were present.



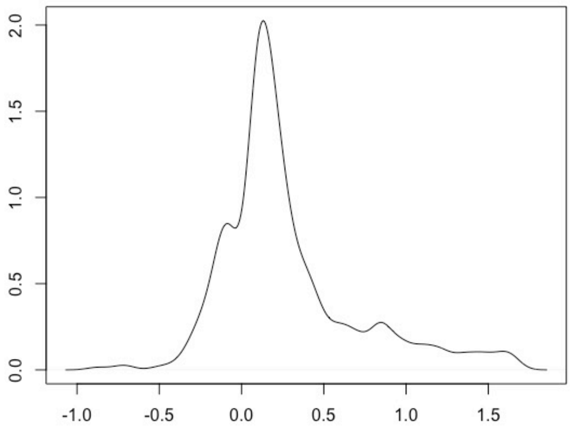
(a) Bilateral Initiation Time



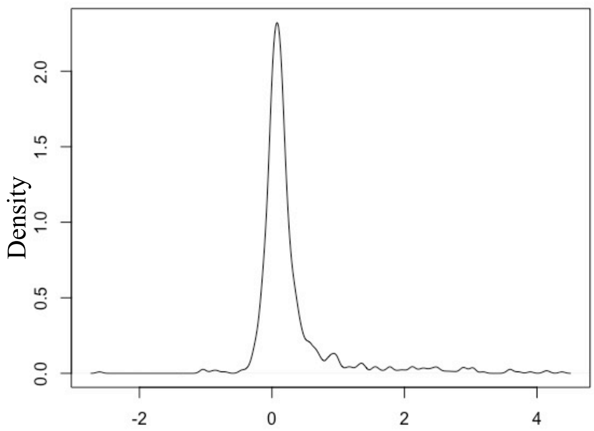
(b) Unilateral Initiation Time



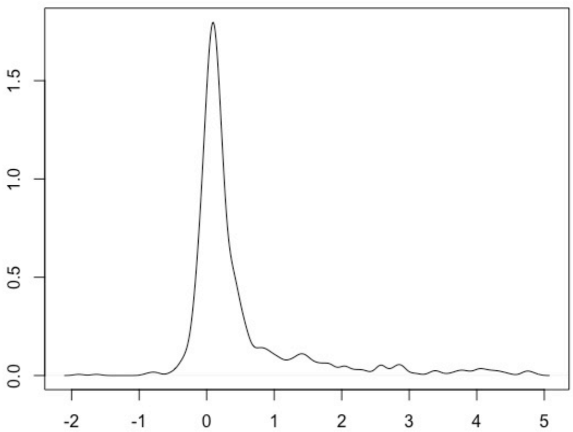
(e) Bilateral Maximum Deviation



(f) Unilateral Maximum Deviation



(g) Bilateral Area under the curve



(h) Unilateral Area under the curve

Figure 5.6. Distributions across bilateral and unilateral conditions for initiation times, response times, maximum deviation and area under the curve, when distractors were absent.

5.5 Discussion

The results of the reanalysis of Experiment 4 demonstrates that initiation times were nearly identical, and RT's were shorter in the bilateral condition although neither difference was significant. However, the response trajectories demonstrated that bilateral cues were more beneficial at the start of each trial resulting in a more direct trajectory and unilateral cues were more beneficial towards the end of the trial. Although the differences between the two response trajectories were marginal and maximum deviation and area under the curve whilst being shorter in the bilateral condition were also not significantly different. These results suggest that there were no clear differences between bilateral and unilateral stimuli when distractors were present.

This directly contradicts the results from Reardon et al (2009) experiments, who found a significant hemifield advantage in tasks when distractors were present and the results from Alvarez and Cavanagh (2005) who found that stimuli in the same hemifield compete for attention. However, this may be due to the data resulting from a reanalysis of a larger experiment. First, the number of eligible trials were relatively small, with only 200 eligible bilateral trials and 213 unilateral trials. It is possible that a larger sample of trials would strengthen the difference between the two conditions. Second, this was part of a larger experiment, as such participants would have become practised at identifying the target. Wolfe, Cave and Franzel (1989) found moderate practice effects in conjunction search tasks (distractors varied in form and colour) and contextual search tasks (finding a 'T' among and 'L'). Cave and Zimmerman (1997) found consistent practice improved search rates when spatial attention tasks (locating a target letter amongst an 8-letter array) and concluded that practice does not eliminate a need for attention but improves the strength and precision in which is allocated. Carrasco, Ponte, Rechea and Sampedro (1998) also found practice effects in feature search tasks (distractor varied in colour) and to a lesser extent conjunction search task (distractor varied in colour and orientation). As participants became more practiced at the task it is possible attentional demands of the task were reduced, Reardon et al (2009) suggested that the additional attentional demands placed on a participant by having distractors present made participants susceptible to a hemifield advantage. Although, the results of Experiment 5 would refute that suggestion as even though distractors were absent there was still a bilateral advantage.

The results when distractors were absent (Experiment 5) demonstrate that RT's were shorter in the bilateral condition, but these differences were not significantly different.

Similar to when distractors were present initiation times were not significantly different in either condition. However, mouse tracking data was able to demonstrate that in the bilateral condition response trajectories were more direct and there were additional mouse movements toward the incorrect response button. The corresponding areas under the curve and maximum deviation was also significantly less in the bilateral conditions. Therefore, the mouse tracking results demonstrated there was a significant bilateral advantage when distractors were absent.

These results are still consistent with the findings from Alvarez and Cavanagh (2005) and the suggestion that each hemifield has different attentional capacities. By being in different hemifields there is more attentional capacity available to aid participants in completing the visual search task and determining the target's orientation. Simply, these results suggest that even before the introduction of additional attentional demands such as distractors it is beneficial to split visual attention across hemifields.

To conclude, the data from RT's alone were unable to demonstrate any hemifield advantages from presenting cues and targets across two hemifields. However, additional data provided by the mouse tracking analysis demonstrated subtle differences when distractors were absent and a bilateral advantage when distractors were not present. These results demonstrate further replications would be worthwhile.

Chapter 6 A replication of gaze manipulation and preference

6.1 Chapter summary

This chapter describes two experiments which aimed to replicate the findings of Shimojo, Simion, Shimojo, and Scheier, (2003) who found that by manipulating gaze (eye movements) it was possible to influence preference. However, the first experiment using the same facial stimuli failed to replicate the experiment. In order to ensure this was not due to the negative attractiveness ratings given to the stimuli, a second experiment was run using computer generated faces. Based on previous replications which suggested that the original findings were due to the mere exposure effect (Bird, Lauwereyns, & Crawford, 2012), the second experiment had three conditions which manipulated duration, repetition and both duration and repetition. The findings suggested that only duration had a small but significant influence on preference.

6.2 Introduction: Experiment 6.1

From an embodied cognition viewpoint, Spivey, Richardson, and Dale, (2009) suggest that perception, cognition and action are all interlinked and therefore it is not just possible to measure cognition by measuring motor activity, but motor activity can also manipulate cognitive behaviour. As discussed in the introduction, Calvo-Merino, Glaser, Grèzes, Passingham, and Haggard, (2004) demonstrated that dancers own motor experiences influenced perception when watching other dancers.

The concept that eye movement between fixation points may provide a measurable indicator of otherwise concealed attentional shifts has resulted in eye movements being widely used as a measure of attention (Kowler, 2011). But consistent with the embodied cognition viewpoint it has also been demonstrated that eye movements may influence cognition. For example, Grant and Spivey (2003) used Duncker's radiation problem (1945) whereby participants were asked to solve the best way to laser a tumour without destroying the healthy tissue surrounding it. The answer was to use low-intensity lasers from multiple locations that converged on the tumour. In the first experiment, Grant et al. (2003) measured eye movements as participants tried to solve the problem. They found that those who found the successful solution sketched the solution with their eyes and eye movements frequently crossed the stomach lining. They concluded that eye movement patterns could indicate whether participants were successful. A second experiment manipulated the salience of the stomach lining through animation and two control conditions either manipulated the salience of the tumour or had no animation. Whilst only a third of participants were able to solve the original problem, two thirds were able to solve the problem when attention was drawn to the stomach lining. It was concluded that eye movements are more than indicators of cognition but potential manipulators of cognition.

Shimojo, Simion, Shimojo, and Scheier (2003) focused on how orientating eye movements does not just enable the search for pertinent information but is also plays an active part in preference decision-making process. To test this hypothesis, they introduced a novel paradigm whereby participants were eventually asked to make a binary forced choice decision as to which male face they found more attractive. The first part of the experiment involved participants rating all faces from 1 (very unattractive) to 7 (very attractive). Based on this rating, faces with the closest ratings were paired together. The faces were alternatively displayed in either the left- or right-hand side of the screen so participants had to shift eye movements between the two options before having to choose which face they preferred. Throughout the trial participants eye movements were monitored. an analysis was conducted on where participants were looking prior to making a decision. Based on the mean decision latency minus one standard deviation every sampling point 1.67 s before a decision was made was given a value. If eye movements were directed towards the eventually chosen face it was given a value of 1, if it was directed towards the alternative face it was given a value of 0. Any other eye movements not directed to the faces were considered to be irrelevant. By averaging across all trials and participants the likelihood that the chosen face was looked at during the decision latency was calculated. This was then plotted against time and a gaze likelihood curve was created. Shimojo et al. (2003) found that whilst the visual attention initially shifted between the two faces before a choice was made there was a gaze bias towards the chosen face prior to it being chosen and a steep rise in the likelihood curve (Figure 6.1).

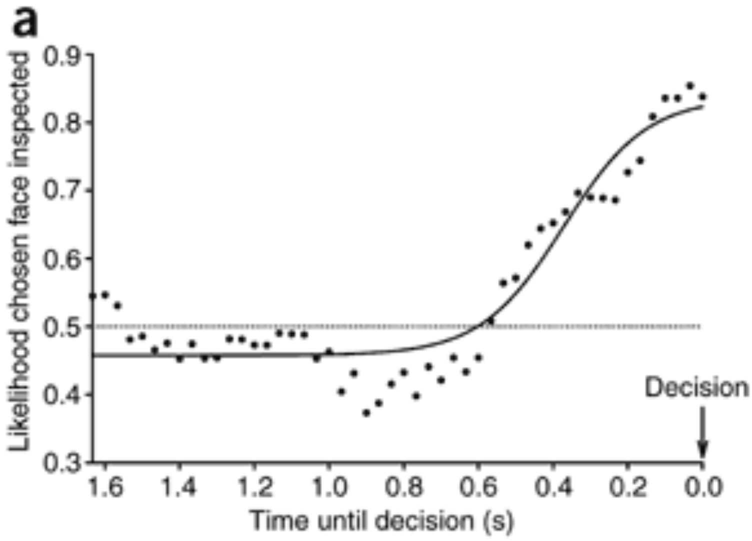


Figure 6.1. Likelihood curve for Experiment 6.1 Face attractiveness Task which plots gaze behaviour against time latency before a decision is made. It demonstrates that initially participants direct gaze at either face at chance levels before increasing to levels above chance thus demonstrating a bias towards the eventually chosen alternative. Taken from 'Gaze Bias Reflects and Influences Preference' by S. Shimojo, C. Simion, E. Shimojo and C. Scheier, 2003, *Nature neuroscience*, *6*(12), 1318.

To explain these results Shimojo et al. (2003) constructed a decision-making model which consisted of both the mere exposure effect where looking at stimuli increases preference (Zajonc, 1968) and preferential looking where participants tend to look longer at the stimuli they prefer (Fantz, 1964). The authors suggest orientating to an object creates exposure which reinforces the likelihood of future orientating behaviour, thus the two processes are integrated by a positive feedback loop whereby "the more we look at a stimulus, the more we like it and the more we like it, the more we tend to look at it." (Simion & Shimojo 2006, p. 1). This feedback loop, known as the gaze cascade, continues until a threshold is surpassed and a conscious decision is made.

To ensure the gaze bias did not occur because participants tended to look at their choice before they selected it or to memorise a response, two control experiments were also run whereby participants had to choose the face they disliked the most and which face was rounder. Whilst there was a gaze bias across all tasks, in the attractiveness task there was a larger effect of gaze bias, contrastingly there was evidence of earlier saturation and lower levels of gaze bias in the control experiments. The authors concluded that these differences meant gaze bias cannot be due to idiosyncrasies found in selecting a response and gaze bias was most prominent in preferential tasks. The authors also re-ran the experiment and participants were asked to rate a set of faces matched for attractiveness then after a delay of a day asked to rate the same pairs of faces on the second day. They found that even when participants changed their mind (this occurred in 23.3% of trials), the participants' eye gaze followed the same pattern and a gaze cascade to the eventually chosen item was found. This led the authors to conclude that this is a process of decision making and not participants relying on memory.

To further test whether a gaze bias occurred because of a response selection mechanics Simion and Shimojo (2006) investigated how early gaze bias occurs by limiting the holistic viewing of stimuli. They used a small window which provided a small foveal view focusing on one feature of the face at a given time (eye, nose, mouth and ear). This was done to make the judgment more difficult and substantially extended the period of time over which a decision could be made thus eliminating the possibility that an internal decision had already been made before the start of the gaze bias. It also eliminated the possibility that an initial holistic judgement was made. Two tasks were given to participants, first participants had to choose the more attractive face and second, as a control, participants were asked to choose the rounder face. Likelihood curves were created for both experiments and consistent with earlier findings, participants demonstrated a gaze bias in the attractiveness tasks and looked at the chosen face around 7.5 seconds before choosing. However, they did not demonstrate a gaze bias in the roundness tasks, looking at the chosen face for less than 1 second before choosing. Simion and Shimojo (2006) concluded that as a gaze bias was only found in the facial attractiveness tasks it only exists in preferential tasks.

Further evidence against gaze bias being a result of selection response mechanics was provided by Simion and Shimojo (2007) who attempted to interrupt the decision-making process. Using the same paradigm participants were asked to rate computer generated faces from Facegen Modeller 3.4 software (www.facegen.com). Faces were rated based on attractiveness on a scale of 1 (very unattractive) to 7 (very attractive). A unique set of 40 male and 40 female faces which had been rated similarly was then produced for each participant. Participants were instructed to choose the most attractive face but the length of time the faces remained on screen varied randomly from 800 ms to 5,000 ms which allocated a random time value to each face. If a choice was made and the faces remained on screen it was called an early decision but if a choice was made and the faces were no longer displayed it was called a late decision. Gaze likelihood curves were drawn based on eye movements to either the face chosen or the blank screen which the face had previously occupied. The authors found that there was a stronger gaze bias to the face chosen prior to the decision made and that this gaze bias was more apparent when the faces had been removed from the screen. They concluded that gaze bias was not the result of decision confirmation but instead a tendency to look at the preferred choice.

Drawing on the evidence provided by gaze bias and to further test the gaze cascade hypothesis, in the second part of the paper Shimojo et al. (2003) carried out a further series of experiments and attempted to manipulate preference by manipulating gaze. According to the gaze cascade hypothesis, visual attention should be influential to preference formation. Rather than repeatedly exposing a stimulus, similar to the mere exposure paradigm, they designed a research paradigm which manipulated gaze and repetition. Participants initially rated a series of faces for attractiveness. Similarly, rated faces were then paired together, however, one was displayed for 300 ms and one for 900 ms. The researchers manipulated how many times the faces were repeatedly shown (2, 6 or 12 times). They also manipulated whether participants would have to shift their gaze and varied how the two faces appeared on the screen. By positioning them horizontally apart (left or right of the screen) or vertically apart (top or bottom of the screen) participants were required to make a saccade from the fixation cross towards the face. Further control conditions were included, and faces were presented centrally or peripherally.

As shown in Table 6.1, eye movement manipulation significantly influenced preference for facial images. This was dependant on a gaze shift occurring as in the conditions when eye movement was not necessary: when faces were only repeated twice on either side of the screen, or were centrally or peripherally displayed, preference was not significantly influenced. It is interesting that duration had a role too as increasing the number of repetitions increased the preference for the longer displayed face.

Table 6.1. Percentage of Times the Face Presented for a Longer Duration was Chosen Based on Each Different Gaze Manipulation

	Gaze shift 2 repetitions (n = 15)	**Gaze shift** 6 repetitions (n = 15)	**Gaze shift** 12 repetitions (n = 13)	**Gaze shift** vertical (n = 15)	**No gaze shift** central (n = 10)	**No gaze shift** peripheral (n = 10)
% longer face chosen	51.2	59.0	59.2	60.2	45.8	49.8
p value *t*-test	0.31	<0.001	<0.005	<0.0001	0.99	0.56

Note. Taken from 'Gaze Bias Reflects and Influences Preference' by S. Shimojo, C. Simion, E. Shimojo and C. Scheier, 2003, *Nature Neuroscience*, *6*2, p. 1318.

This experimental design has been replicated in other studies with appetitive food. By using the paradigm in conjunction with fMRI experiments and appetitive food choices, Lim, O'Doherty, and Rangel (2001) attempted to answer whether visual attention influences the computation of relative value signals during the decision-making process.
First, participants performed one liking task rating 60 different food on a five-point scale. Second, participants were given a binary choice trial and asked to choose between two food items. To direct participants eye movements to alternating food items, a green or red frame surrounded each choice, and individuals were given a target colour to find. The duration of eye movement fixation varied from 1 to 4 seconds in 1 second increments and target position were randomly switched across trials. At the end of the trial participants received an item from a randomly selected trial. To ensure the attention manipulation had occurred eye movements were recorded. Lim, et al. (2001) found that the ventromedial prefrontal cortex (vmPFC) and ventral striatum (vStr) correlated with encoding of a relative value signal during the decision-making process. More relevantly, they found visual attention manipulation had a reliable but small impact on food choice.

This concept of visual attention influencing the decision-making process has also been incorporated into models of decision making. As discussed in the introduction, Krajbich, Armel, and Rangel (2010) extended their attentional Drift Diffusion Model (aDDM) of decision making to include the role of visual attention on binary choice. The model is based on the idea that information is continuously accumulated over a trial until a threshold is reached for either option a or option b. Specifically, the model assumes that when making a decision, values known as the relative decision value. Before each trial this value starts at 0 but is continuously integrated and recomputed over time until it reaches a threshold of either +1 (left item is chosen) or -1 (right item is chosen). The model suggests that visual attention and fixations play a particularly important role in the process of influencing this value and fixation location in particular impacts the rate in which a decision is made. It makes several predictions about the relationship between visual attention, choices and RT's. For example, the model predicts participants are more likely to choose the item they look at last unless that item is considered to be far more negative than the alternative and the longer you look at an one choice the longer you will have to look at the alternative before a decision is made.

Whilst the previous chapters have used motor activity as a measure of cognition the aim of the current study was to replicate Shimojo et al.'s (2003) second gaze manipulation experiment which specifically hypothesised that visual attention can influence the decision-making process in preference formation. Whilst Shimojo et al. (2003) displayed the faces both horizontally and vertically and the largest effect was found with the vertical display, Shimojo et al. (2003) explored the role of repetition with only horizontally displayed faces. Of which the largest impact of manipulation was found when participants were repeatedly shown the faces for 6 repetitions. Once the effect for 6 repetitions has been established it will then be possible to examine the role repetitions plays in the gaze cascade theory and why in Shimojo et al.'s (2003) experiment repeating the image display twice did not produce an effect. It will also be possible to further explore the role duration has in the effect. Rather than explore eye movements the aim of the study is to mimic the basic behavioural effect. It is worth noting at this point that subsequent research has questioned the role of eye movements in the effect, although this will be discussed in more detail further on (Nittono & Wada, 2009; Bird, Lauwereyns, & Crawford, 2012).

6.3 Method: Experiment 6.1

Participants. Sixteen members of the public aged between 20 and 38 took part in the experiment. All participants had self-reported normal or corrected-to normal vision.

Materials and Stimuli. For half the participants images were presented on a 1024 x 768 pixel laptop and for the other half a 1280 x 1024 pixel monitor. The stimuli consisted of 66 neutral colour faces (33 female and 33 male) selected from the Ekman Face database (Ekman & Friesen, 1976) as used by Shimojo et al. (2003), see Figure 6.2 for examples. Each face was 562 x 762 pixels. Responses were collected via a standard USB keyboard connected to the PC used to control the experiment. The experiment was programmed in Matlab 2012a, using the Psychophysics Toolbox extensions (Brainard, 1997; Pelli, 1997; Kleiner, Brainard, & Pelli, 2007).

Figure 6.2. Example of female and male faces from the Ekman face database (Ekman & Friesen, 1976) as used by Shimojo et al. (2003).

Design and Procedure. The experiment consisted of two phases: Stimulus Rating and 2AFC. In the Stimulus Rating phase participants were asked to rate a series of centrally presented individual faces on a scale from '1 (very unattractive)' to '7 (very attractive)' using the numerical keys on the keyboard. A total of 66 faces were presented; the order that the faces were presented was randomised for each participant. Faces were presented on screen until response.

In the 2AFC phase pairs of faces of the same gender were created based on the ratings given in the first part of the experiment. Faces were ranked in order of rating and then paired together if they received the same rating or a rating no greater than one-point difference. The number of face pairs for each participant depended on the match criteria and ranged from 29 pairs to 31 pairs of faces.

The first face of the pair (Face A) would appear on either the left or right (randomly chosen on each trial) of the screen at the vertical centre, 50 pixels from the horizontal centre of the screen. The image would then disappear and the second face of the pair (Face B) would appear on the opposite side. Each face was alternatively shown on either the left-hand or right-hand side of the screen a total of six times. One face, in the Long condition, was shown for 900 ms and the other face, in the Short condition, for 300 ms. Once the faces had been displayed six times each, participants selected the face that they preferred, by pressing the left or right arrow on the keyboard corresponding to the side of the screen on which their preferred face appeared. Whether the duration condition was presented first and whether the highest rated face was presented first was randomised. The experiment lasted approximately 40 mins.

6.4 Results: Experiment 6.1

The average response time for each response was 2.16s. There was no significant difference between preferences for faces. A one sample t-test was run on the data whereby the faces in the long condition was chosen less often (M = 47.44, SD = 0.11) than the average of 50%, a statistically non-significant mean difference of 0.02, 95% CI [-0.08 to 0.03], $t(15) = -0.95$, $p > 0.05$, $d = 0.24$.

This experiment therefore failed to replicate the finding that face duration influenced preference. Out of 16 participants, only 6 showed an overall preference for the face shown for the long duration.

During the rating part of the experiment, whereby participants had to rate faces on a scale of '1 (very unattractive)' to '7 (very attractive)', the face stimuli used mainly received unattractive ratings with an average rating of 2.8 with a standard deviation of 1.35. The average minimum rating given was 1.44 and the average maximum rating given was 5.25.

6.5 Discussion: Experiment 6.1

The results demonstrate that this experiment did not replicate the findings of Shimojo et al. (2003) who found that increasing repeating faces on either side of the screen for 6 repetition influenced preference. This failure to replicate may have been due to the low attractiveness ratings given to each face which may have meant that participants did not develop a liking for any faces and therefore did not engage with the task.

The finding that images shown in the long condition were actually chosen less often, although not reliability so, maybe because the increased exposure increased negative judgments of the images. Armel, Beaumel, and Rangel (2008) replicated the gaze manipulation paradigm by Shimojo et al. (2003) for appetitive food, aversive food items and art posters (neutral condition). They found appetitive items and neutral items were more likely to be chosen in the long fixation condition whereas aversive items were less likely to be chosen.

However, in a replication by Ito, Wu, Marutani, Yamamoto, Suzuki, Shimojo and Matsuda (2012) the authors were able to change participants preference by using the Shimojo et al. (2003) paradigm. Whilst monitoring brain activity through fMRI of the hippocampus and orbitofrontal cortex, participants were asked to make two forced choice alternative decision. Participants were split into two groups: the main manipulation group or the control group. The main manipulation group took part in an initial choice experiment whereby they had to choose from two faces the face they would prefer to approach and talk to. Participants then either took part in a non-manipulation task where gaze was not manipulated and the faces from the initial choice phase were presented in the centre of the screen for 600 ms; or a gaze manipulation task whereby the preferred face from the initial choice experiment was shown for 300 ms and the unchosen face 900 ms. All participants then had to complete a final choice phase, similar to the initial choice, and decide which face they would rather approach and talk to. The control group completed the same phases of the experiment but were instead asked to choose the rounder face. Participants were only found to have changed their mind in the preference task, when exposure was manipulated.

Shimojo et al. (2003) also states that gaze bias, a key component of the gaze cascade theory, only occurs when choosing the option you prefer. There should, therefore, be strong evidence of gaze bias in preference decisions only. However, subsequent replications have challenged this and found a gaze bias in a variety of tasks. Using the same method as Shimojo et al. (2003) initial task but with novel graphic images Nittono and Wada (2009) failed to find evidence of gaze bias in preference tasks alone. In the first experiment, participants were given three different tasks; a like task whereby they chose the figure they preferred, a dislike task whereby they chose the figure they disliked the most and finally a brightness task in which they chose the figure they thought was brighter. A gaze bias towards the eventually selected response was found in all decision-making tasks.

Whilst the likelihood curves of each study resembled those of Shimojo et al. (2003) it was concluded that participants tended to look at the option they ultimately chose before their decision, irrespective of judgement type challenging the gaze cascade hypothesis. Further analysis also revealed that this was not found in all single trials but was the results of averaging gaze shifts in hundreds of trials.

Glaholt and Reingold (2009a) also tested the generality of the findings of the gaze cascade hypothesis to preference tasks using black and white photographic art. Using a similar paradigm to the one used by Shimojo et al. (2003) in their initial experiment, participants were asked to choose which photograph they preferred and, in a control experiment, asked which photograph was taken more recently. However, participants were given an eight alternative forced choice task to lengthen the experiment so a comprehensive time course could be created, and eye movements were recorded. A gaze bias to the chosen stimuli was found across all tasks further challenging Shimojo et al.'s (2003) findings that this occurs in preference tasks only. The authors suggested preferential decisions are not different from other decisions and gaze bias reflects a general aspect of visual decision making. Interestingly, the eight alternative forced choice experiment did demonstrate an early gaze bias suggesting that people actively engage in evaluating items during encoding and this top down process of visual attention may lead to increased viewing times of eventually chosen items.

Zommara, Takahashi, Ounjai and Lauwereyns (2018) studied gaze bias not with a visual preferential task but with a choice optimisation task. Using the Iowa Gambling Task, which requires participants to actively learn the validity of different choice options, participants either had to use a mouse to choose a response or, to rule out the possibility of hand eye coordination influencing the results, respond via a keyboard. Both results showed a clear gaze bias towards the preferred choice and provide evidence of gaze bias in non-perceptual decision making.

Further replications have questioned the gaze cascade hypothesis as an explanation for gaze bias. Schotter, Berry, McKenzie, and Ranger (2010) gave participants four different tasks involving a variety of pictures of landscapes, portraits, animals and architecture. Pairs from the same genre were displayed in the 2 alternative forced choice decision. Subjects were asked to make one of four decisions; which one do you like more (like) which one do you like less (dislike), which one is older? (older) and which one was taken recently (recent). Analysing the first dwell time on each item, participants were slightly more likely to choose the first item they looked at and direct the last gaze to the chosen item. This effect occurred across all tasks, although the magnitude of this effect was greater in the liking tasks. The authors concluded that this is the result of a liking effect/preferential looking whereby selective encoding is aided by the liking effect but when choosing a disliked item, the gaze effect the liking effect competes with selective encoding reducing its impact. Also contrary to the positive feedback loop prediction, as the trial progressed gaze bias did not become more amplified and the authors found no interactions between gaze bias and decision type as the trial progressed. It was concluded that preferential looking and gaze bias are two separate processes rather than being part of a positive feedback loop.

Morii and Sakagami (2015) asked participants to make a two alternative forced choice between two nonsensical visual patterns and tracked eye movements. Using stimulus elimination techniques whereby the stimuli was removed after a specific interval they found that gaze was directed to the chosen alternative before the stimuli was removed as suggested by the gaze cascade hypothesis. However, the authors suggest that the gaze bias could be explained by participants preparing to respond.

Onuma, Penwannakul, Fuchimoto and Sakai (2017) gave participants a two alternative forced choice with images of human faces, red wine bottles and snacks whilst monitoring eye movements, specifically the order of dwells. They found that the chosen item was looked at for longer than the not chosen item but only after participants had reviewed both items. The authors concluded that whilst participants evaluate items during encoding (selective encoding) early on in visual decision making it does not occur in the initial encoding stage.

As a result of these replications it is unclear whether gaze bias is a result of the gaze cascade mechanism or just a response phenomenon or, if longer exposed choices are chosen more often as a result of a positive gaze cascade feedback loop. In order to explore this further, first, we must replicate the results of gaze manipulation experiment. This may be more likely to occur if more 'attractive' stimuli are used so participants engage with the task and there is a wider spread of ratings across the faces. Second, given the strength of the mere exposure research it would be interesting to explore the role length of exposure plays in preference.

6.6 Introduction: Experiment 6.2

Further replications of the gaze manipulation experiment have failed to replicate that manipulating eye movements can influence preference. Nittono and Wada's (2009) second experiment attempted to replicate Shimojo et al. (2003)'s gaze manipulation experiment using novel graphic image choices, these were presented 6 times for 300 ms or 900 ms but were either in left versus right positions or centrally presented. Participants chose the longer face 56% of the time when a gaze shift was required and 58.1% in the central condition. The authors, therefore concluded that the effect was driven not by gaze shift but simply by the mere exposure effect.

Further investigations into gaze bias behaviour also suggests that eye gaze movement is not important, but the critical factor is the gaze fixation and the amount of time which is spent gazing at the stimuli influences preference. Gunia and Murnighan (2015) focused on purchasing decisions as participants do not just choose based on preference but also have to integrate preference with price. By using a variety of posters of items such as paintings and cars, in a series of experiments the authors asked participants to rank items in order of preference. The posters were then presented with prices by manipulating the prices on the item preferred and recording how long each participant spent looking at each poster. They found that viewing time provided insight into preference when prices were absent or moderately at odds with preference concluding that in this scenario viewing reflects preference and encoding processes that direct attention to the preferred choice. However, viewing time did not provide insight to preference when prices strongly conflicted or supported preferences. The authors concluded that in this scenario viewing reflects preference and encoding processes that causes attention to diverge in multiple directions reducing attention on the preferred option.

Glaholt and Reingold (2009b) also attempted to manipulate stimulus exposure but rather than increasing the duration of stimuli they pre-exposed participants to four photographs before giving participants an eight-alternative decision task and monitoring their eye movements. A control experiment was also included whereby participants had to choose the photograph which was most unusual. Gaze cascade theory predicts that increasing stimulus exposure should result in stronger gaze bias and preference effects. Crucially, participants did not choose the pre exposed photograph more often nor was gaze directed to the pre-exposed items more often; dwells to pre-exposed photographs were shorter in duration than non-pre-exposed items. Glaholt and Reingold (2009b) suggested that vital information was obtained from the pre-exposed stimuli, therefore more time was spent on the non-pre-exposed items to evaluate the information they provided. This contradicts the theory of preferential looking which suggests the more you look at it the more you like it. In terms of gaze bias, whilst there was a tendency for gaze to be directed to the chosen stimuli before the decision was made, this did not depend on whether an item was pre exposed nor was it only apparent in the preference task. The authors concluded that gaze bias reflects a general characteristic of visual decision making rather than being specific to a gaze cascade hypothesis.

To rule out the possibility that increased exposure needs to occur during the ongoing decision, rather than before it to significantly impact preference, Glaholt and Reingold (2011) designed a further test using their eight-alternative decision task paradigm. When participants directed their eye gaze towards a choice the stimulus was then removed from the display after either a short duration (200ms) or a long duration (400ms). The alternative reappeared only when gaze moved to a different alternative. Participants took part in two tasks, a preference task and a typicality task, where they had to pick the picture which was the most unusual. The long duration item was chosen significantly more often, however, contrary to the gaze cascade hypothesis prediction this occurred in both tasks. The authors suggested that this could occur because participants were not able to extract enough information from the short exposure items to confidently choose them.

One of the most direct replications of Shimojo et al.'s (2003) gaze manipulation experiment was by Bird, Lauwereyns, and Crawford (2012). The authors suggested that previous failures to replication Shimojo et al. (2003)'s findings may have occurred because of the different stimuli that were used. One replication which used different stimuli was by Park, Shimojo and Shimojo (2010) who asked participants to perform a two forced choice task in which they chose either faces, natural scenes or geometric stimuli on the basis of familiarity or novelty. They found familiarity was more dominant with facial stimuli, and novelty was more dominate in natural scenes. No bias was observed with geometric stimuli. To test whether this was a task related phenomenon Liao, Yeh and Shimojo (2011) adapted the paradigm to test if passive or objective tasks affected the results. They replicated the findings that preference biases exist across object categories with objective tasks but also found that only passive viewing causes preferences for familiar faces, supporting the view that preference formation is dependent on types of stimuli.

In relation to the finding by Nittono and Wada (2009) that gaze was not required, Bird et al. (2012) also suggested that presenting faces centrally may result in inter-stimuli interference; by presenting a new face in the same location as the previous face may disrupt the visual processing of the previous face. In order to address these possibilities, they designed a replication of Shimojo's experiment with three experimental conditions; first, lateral attractiveness whereby faces would be displayed side by side for either 300 ms or 900 ms for 7 repetitions. Second, central attractiveness non masked condition where faces were displayed for the same times and repetition but were displayed centrally. Third, central attractiveness masked condition whereby faces would be displayed centrally but with an inter stimulus mask of random black and white dots for 50 ms.

Table 6.2. Percentage the Face Presented for a Longer Duration was Chosen Based on Each Different Gaze Manipulation

	Lateral attractiveness	**Central attractiveness non masked**	**Central attractiveness masked**
% preference for longer face	55.83	53.44	53.94
p value *t*-test	<0.001	0.056	<0.01

Note. Reprinted from 'The role of eye movements in decision making and the prospect of exposure effects' by G.D. Bird, J. Lauwereyns, and M.T Crawford, 2012. *Vision Research*, *60*, p. 20.

As shown in Table 6.2, in line with the findings by Nittono and Wada (2009) presenting faces centrally resulted in the longer face being chosen. This result led the Bird et al. (2012) to conclude that eye movements did not influence preference, but stimulus duration was key in influencing preference as a result of the mere exposure effect.

However, it is unclear whether stimulus duration was driven by the facial stimuli being displayed for longer or whether the increased duration allowed participants to repeatedly sample each face. In Bornstein's (1989) meta-analysis on Zajonc's research (1968) on mere exposure it was highlighted that the mere exposure effect is stronger when duration is short and there is no conscious awareness. This issue of conscious awareness has dominated much of the literature researched to date (Zajonc 1980; Bornstein 1992; Monahan, Murphy, Zajonc 2000). Many studies have explored the influence of exposure's role when participants have no explicit memory (Kunst-Wilson & Zajonc, 1980). Bornstein and D'Agostino (1992) presented participants with either polygon stimuli, photographic images or line drawings for either a 5 ms duration or 500 ms; 0, 1, 5, 10 or 20 times. After each exposure a 100 ms mask appeared. Participants were given a liking task and rated the stimuli on a 9-point rating scale. To check whether the images were subliminal an additional discrimination task was used on some participants to see if they recognised the stimuli. Increasing exposure frequency was linked with increased liking ratings and presenting stimuli for a shorter 'subliminal' 5 ms resulted in a greater mere exposure effect. As a result of this research you would not expect the mere exposure effect to occur with durations of 900 ms and 300 ms as increased awareness of stimuli would negate the mere exposure effect however, increasing frequency such as the repetitions used by Bird et al. (2012) may have had a greater influence on preference.

Newell and Shanks (2007) also replicated Bornstein and D'Agostino's (1992) study and ran 3 experiments. First, they presented participants with photographs of neutral faces. In the exposure phase, participants were shown the stimuli for either 400 ms or 40 ms using a rapid serial visual presentation each face either appeared 9 times or 3 times. They then were given a recognition task, 'Which face have you seen before', or a preference task, 'Which face is more likeable'. Participants reported that the faces were difficult to like because of a neutral expression (similar to our findings in experiment 6.1). Therefore, a second experiment was run with positive smiling faces and a final experiment used polygon stimuli. To avoid the possibility of the 400 ms face surpassing the 40 ms face in comparison a between-subjects design was employed. The experiments then followed the same paradigm, and appeared for either 400 ms or 40 ms, 9 times or 3 times. Unlike Bornstein and D'Agostino's (1992) study which found increasing duration inhibited the mere exposure effect, in all three experiments the authors found that frequency and duration had an impact on recognition and a significant mere exposure effect was only found when recognition was high.

The finding that the mere exposure effect only exists without conscious awareness has been challenged in subsequent research. De Zilva, Vu, Newell and Pearson (2013) replicated the experiment using continuous flash suppression. This paradigm allows longer durations to be used without participants becoming aware of the stimuli. The target stimulus is presented to one eye whilst visual noise or Mondrian patters are continuously shown in the other eye. These second high-energy visual stimuli are more dominant for the participant and can suppress the target stimuli. During the exposure phase of the experiment target stimuli (contours or facial stimuli) were presented to participants either 0, 1, 10 or 20 times and were either suppressed or unsuppressed. In the second part, participants undertook a recognition task and a preference task, rating items on a 7-point scale. With both stimuli the experimenters found that increased frequency increased recognition and preference was only impacted when participants were consciously aware of the stimuli.

These studies have two implications, first it suggests the mere exposure effect can occur when participants are aware of the stimuli supporting Bird et al. (2012)'s explanation and second, it highlights that duration and frequency/repeated sampling should have an influence on preference. The aim of the next experiment was to discover first, if it is possible to influence preference by using more attractive stimuli. To address this, as the facial stimuli used in Experiment 6.1 were not deemed attractive by participants (they had a low average rating and small standard deviation) rather than use the same faces this experiment will use the same computer-generated faces used by Bird et al. (2012). Second, to investigate whether the duration of an item or repeated sampling influences preference, this experiment will manipulate first, the duration the facial stimuli appears on screen, second, the amount of times a participant is exposed to a face (repetition) and in a final condition, both duration and repetition of the faces will be manipulated.

6.7 Method: Experiment 6.2

Participants. To increase power the sample was increased to twenty-eight undergraduate students (24 female) from the University of Bristol who completed the experiment for course credit. All participants had normal or corrected-to normal vision.

Materials and Stimuli. Images were presented on a 1280 x 1024 pixel computer monitor. The stimuli consisted of 108 computer generated faces (54 male and 54 female) as used by Bird et al. (2012). The faces had been generated from Facegen Modeller 3.4 software (www.facegen.com) where they had been selected to be between 20 and 30 years old, average attractiveness, absolute symmetry, European/white, and female – very female or male – very male. The size of each face was 574 x 454 pixels.

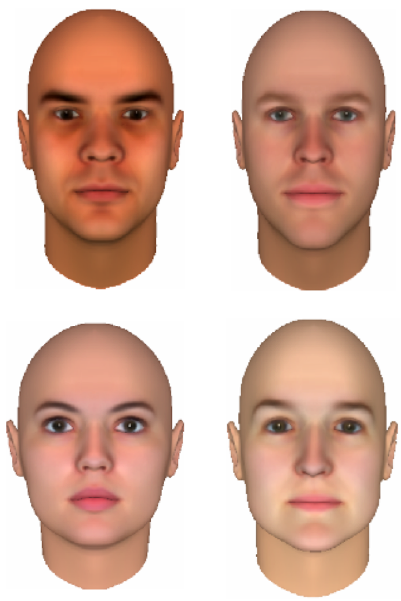


Figure 6.3. Example of male and female computer-generated faces as used by Bird et al. (2012).

Design and Procedure. The design and procedure were identical to Experiment 6.1 with the following exceptions. We manipulated both the duration faces were presented for (either 300 ms or 900 ms) and how many times a face was repeated (6 or 18). In the Long condition, faces were shown for 900 ms and in the Short condition they were shown for 300 ms. In the Many repetitions condition the faces were shown for 300 ms 18 times, in the Few repetitions condition faces were presented for 300 ms 6 times, see Table 6.3.

Table 6.3. Duration and Frequency (ms) Manipulation the Faces Were Displayed in Each Condition.

	Long vs Short	**Many vs Few**	**Short-Many vs Long-Few**
Duration (ms)	900/300	300/300	300/900
Frequency	6/6	18/6	18/6

In the final two conditions, we equated total duration so that one face was presented for 300 ms 18 times (Short-Many condition) and the other for 900 ms 6 times (Long-Few condition), a shown in Table 3. Conditions were paired such that the Long and Short conditions occur on the same trials, the Many and Few conditions occurred on the same trials, and Short-Many and Long-Few conditions occurred on the same trial. Pairing of faces were created using the same method as in the previous experiments; whereby faces were ranked in order of rating and then paired together if they received the same rating or a rating no greater than 1-point difference. The number of face pairs for each participant depended on the match criteria and ranged from 29 pairs to 31 pairs of faces. Each condition was then randomly allocated 18 pairs of faces.

6.8 Results: Experiment 6.2

Ratings. Across all participants the average rating for the computer-generated faces in the rating task was a score of 3.12, the average minimum rating was 1 and the average maximum rating was 7.

Significance testing. It was only possible to significantly influence preference in the Long duration condition. A one sample t-test was run on the data whereby a face displayed for a longer duration was chosen more often (M = 53.97, SD = 10.13) than 50%, a statistically significant mean difference of 3.97, 95% CI [0.04 to 7.90], $t(27) = 2.07$, $p < .05$, $d = 0.39$.

In the Many condition, the face shown repeatedly for 300 ms had no impact on preference and was chosen in an average of 50% of trials across participants. A one sample t-test was run on the data whereby the longer displayed face was chosen 50% of the time (M = 50.00, SD = 11.52), a mean difference of 0.00, 95% CI [-4.47 to 4.47], $t(27) = 0.00$, $p > 0.05$, $d = 0.00$.

In the final condition, Short-Many vs Long-Few, the face shown for 300 ms 18 times was chosen on 52.18% of trials and the face shown for 900 ms 6 times was chosen 47.82% of trials. A one sample t-test was run on the data whereby the longer less repeated displayed face was chosen less often (M = 47.82, SD = 14.37) than the average of 50%, a mean difference of -2.18, 95% CI [-3.39 to 7.76], $t(27) = -.804$, $p > 0.05$, $d = -0.15$.

Overall, it would appear that only by increasing duration it is possible to significantly increase preference, albeit by relatively small amounts.

6.9 Discussion: Experiment 6.2

Similar to the findings of Shimojo et al. (2003), Nittono and Wada (2009) and Bird et al. (2012), by using less 'unattractive' faces, it was possible to influence preference when displayed for a longer duration. Although the attractiveness ratings for the computer-generated faces were still low in this experiment (average rating of 3.12) they were higher than those of the first experiment (average rating of 2.8). This effect of duration influencing preference is consistent with Mere Exposure theory to a degree as increased preferences have been linked with increased familiarity and a positive emotional response (Zajonc 1968). However, contrary to Bornstein and D'Agostino's (1992) and de Zilva, Vu, Newell and Pearson (2013) study, the effect was not found in the Many condition when the frequency of exposure was increased. This suggest the mere exposure effect was not driven as a result of the stimuli being sampled repeatedly (looking at the facial image an increased number of times). Therefore this also contradicts many of the current theories of mere exposure, such as Zajonc et al. (2001) who suggests repeated sampling coupled with a lack of negative response can create a conditioned response, or Perceptual Fluency Theory (Bornstein & D'Agostino, 1992, 1994) which specifically states that increased sampling enhancing processing ease, speed, and 'fluency' of perception which can then be misattributed to liking.

As mentioned earlier, Bornstein and D'Agostino's (1992) and de Zilva, Vu, Newell and Pearson (2013) experiments are not directly comparable to Experiment 6.2 as duration, frequency and awareness may have been confounded; participants were not aware of stimuli presented for 40 ms. Given the focus in the mere exposure literature on subliminal awareness few have manipulated conscious duration alone. However, Reber, Winkielman, and Schwartz (1998) displayed visual patterns to participants for either 100, 200, 300, or 400 ms, respectively followed by a mask of 250 ms. The positive group were asked: 'do you like the pattern?' and the negative group were asked: 'do you dislike the pattern?'. For both groups' participants preferred the stimuli which had been presented for a longer period of time. The authors concluded that this was because a longer duration increased perceptual fluency. Perceptual fluency theory (Bornstein & D'Agostino, 1992, 1994) proposed that repeated exposure to neutral stimuli enhances processing ease, speed, and 'fluency' of perception which is then misattributed to liking.

Based on the results of Experiment 6.2, increasing repetition and duration had the opposite effect and resulted in theses faces being chosen less often. The gaze cascade hypothesis would suggest that increased looking would result in increased preference. Whilst this may also seem contrary to the mere exposure effect, in Bornstein's (1989) review of the mere exposure effect, it has been demonstrated that there is often a ceiling effect after a relatively small number of exposures to a stimuli and even a decline in the mere exposure effect as the number of exposures increases. Szpunar, Schellenberg and Pliner (2004) exposed participants to different musical excerpt for equal durations for either 2, 8 or 32 times. They reliably found that after 32 exposures satiation effects of frequency on liking. It may, therefore, be possible that the lack of results in these conditions were due to over exposure.

Whilst it is possible to influence preference from duration, this effect is small. The maximum reported effect from the studies to date by Shimojo et al. (2003) was 60.2% preference for the longer face shown in the vertical gaze manipulation study. It is possible that this is due to experiments being run with relatively small numbers of participants. Ioannidis (2005) demonstrated that if you explore the different elements of scientific research process it can lead you question how many biomedical research positive findings may be false (type I error, null hypothesis rejected when true). He explored multiple issues of scientific research and suggested a combination of the following impacted false findings such as: a reliance on a statistical significance of a p-value less than 0.05; small effect sizes; a bias during design and analysis of an experiment towards a research finding; influences from the scientific field such as public and financial interest in the area; flexible research designs and more relevantly the size of the experiment. Small sample size has long been linked with lower statistical power (Cohen 1988). For clarity, the power of a statistical test is the probability that a type II error has not occurred: when the null hypothesis is false and not rejected (Shaughnessey, Zechmeister, & Zechmeister, 2012). Running small studies have been linked with low statistical power not only due to the problems that arise mathematically but due to biases becoming magnified in small studies (Button, Ioannidis, Mokrysz, Nosek, Flint, Robinson & Munafo, 2013). Button et al. (2013) suggest studies with low power are more likely to contribute to a lower chance of finding an effect that exists, low probability that a positive research finding is actually true and exaggerated effects of the strength of the effect.

Shimojo et al. (2003), Simion and Shimojo (2006, 2007) and Nittono and Wada (2009) used between 10 to 15 participants in a between subject design whilst Bird et al. (2009) used 48 participants in a within-subject design. Whilst within-subjects/repeated measures designs are more sensitive because by using the same participants in each condition the variation in participants or error variation is removed and therefore, they are likely to have higher power (Shaughnessey, Zechmeister, & Zechmeister, 2012). It is therefore possible due to the low sample size and associated low power that the Shimojo et al. (2003) finding may be false positives or the strength of the manipulation was exaggerated. The next experiment therefore will use a larger sample size to better estimate the effect size for a large sample and the associated power needed to detect these effects in future research.

Chapter 7 Mouse tracking duration and repetition effects on preferences

7.1 Chapter summary

This chapter described two experiments which investigate how increasing duration of facial stimuli may influence preference using the same paradigm as in the previous chapter. However, unlike the previous chapter mouse tracking will be used to measure participants responses and a large number of participants will take part in each experiment. The first experiment demonstrates that consistent with previous findings, duration had a small but significant influence on preference. No differences were found in the mouse tracking analysis. In order to ensure participants had not already decided on a response before moving their mouse; in the second experiment, facial stimuli were displayed once, and only duration was manipulated. The results demonstrated that it is possible to manipulate preferences for facial imagery by only manipulating duration for faces although no significant differences were found in the mouse tracking analysis.

7.2 Introduction: Experiment 7.1

In order to reliably conclude that there was an effect for duration, a further study was undertaken whereby a large group of participants undertook the duration phase of experiment 6.2. However, in these experiments the response trajectories of participants were recorded whilst they made their decisions.

As mentioned earlier, subsequent replications of the Shimojo et al (2003) study attempted to extend the task to allow for a more detailed analysis of the time course of decision making. Simion and Shimojo (2006) used a small gaze contingent windows to increase difficulty and stop participants producing preference and internal decisions quickly. By presenting an image in small pieces they were able to significantly lengthen the experiment and link early gaze bias with preference. In Glaholt and Reingold’s (2009a) study as well as introducing an eight alternative forced preference choice paradigm, in one experiment they also used small contingent windows. This allowed them to have a more comprehensive analysis of the time course of gaze behaviour and they were able to analyse dwell duration and dwell frequency. Across all experiments the authors found that there was a robust early gaze bias towards the chosen item however, they concluded this effect was not task specific but a general aspect of visual decision making.

As mentioned in previous chapters hand movements have been deemed to reflect online cognitive processes (Spivey, Richardson & Dale, 2009; Freeman, Dale & Farmer, 2011). By using mouse tracking software, response trajectories recorded by a computer mouse have been thought to track participants thought processes when presented with choice alternatives to provide a time course of information processing. Mouse tracking can not only provide RT's (RT), initiation times (IT), it also possible to plot response trajectories and quantify differences in response trajectories using variables such as Maximum Deviation (MD) and the Area Under Curve (AUC).

The aim of the first experiment was to replicate the findings from the previous experiment, that duration could influence preference. As it is expected that participants move their mouse as soon as possible so initiation times should remain similar across conditions. The faces which are displayed for longer may result in faster RT's. Faces which are displayed for longer should result in an increased preference for the longer face. If increased durations result in greater certainty of preference, it would be expected that RT's are shorter in the long condition, response trajectories are more direct and the maximum deviations and areas under the curve are smaller.

7.3 Method: Experiment 7.1

Participants. A post hoc power analysis was conducted on the previous experiment using the software package, G*Power (Faul, Erdfalder, Lang, & Buchner, 2007). The sample size of 28, cohen's *d* effect size of 0.39, and an alpha level of .05 revealed the statistical power for this experiment was 0.64 for detecting a small effect. Therefore, there was less than adequate statistical power at the small effect size level. A priori power analysis indicated 43 participants were required in total to have 80% power for detecting a small sized effect (0.39) when employing the traditional .05 criterion of statistical significance (Faul, et al., 2007). Due to the recruitment process, one hundred and three undergraduate students from the University of Bristol completed the experiment for course credit.

Materials and Stimuli. Images were presented on a 21" 1,920 x 1,200 pixel computer with 60 HZ refresh rate. The stimuli were presented in a darkened room. Participants sat approximately 50 cm from the screen and had to move a mouse placed on the right-hand side of a desk to respond.

The faces were identical to the computer generated faced used by Bird, Lauwereyns, and Crawford (2012) in Experiment 6.2. This experiment did not include a rating phase. The ratings given to the faces in Experiment 6.2 were used to generate pairs of similar rated faces. Any faces with a standard deviation greater than 1.25 were removed. The face stimuli were then paired together based on their mean score of attractiveness and sex. Any pairs with a difference in mean greater than 0.25 were removed. As a result of this screening there were 14 male pairs and 13 female pairs.

The MouseTracker space represents a 2 x 1.5 rectangle, the start button and start of all response trajectories is located in the bottom centre of the screen (co-ordinates 960 px, 0 px). One response button (384 px x 240 px) was located at the top left-hand side of the screen (co-ordinates 0 px, 1200 px) and the other response button (384 px x 240 px) was located at the top right-hand side of the screen (co-ordinates 1536 px, 1200 px).

Design and Procedure. Participants were split into two groups. For Group A, on 50% of trials Face A would appear on the left-hand side of the screen first before the image would disappear and the second face of the pair, Face B, would appear on the right-hand side. In the other half of the trials, Face A would appear first on the right-hand side and Face B would appear on the left-hand side. Whether the face appeared first on the left or right was counterbalanced and for 50% of trials Face A was the higher rated face. For Group B, the faces appeared on the opposite side to Group A.

Participants initiated each trial by clicking on the start button which was located at the bottom centre of the screen, the faces then flashed alternatively on screen. Face A for 900 ms and Face B for 300 ms. Once both faces had appeared 6 times, each face would then appear at the top hand corners of the screen and the participants were able to move their mouse and select which face they preferred. If a response was not made after 9,000 ms a 'time out' message would appear, and the trial would end. The experiment lasted approximately 5 min.

7.4 Results: Experiment 7.1

Exclusion criteria. Trials were excluded when they were initiated later than 1,500 ms, (as a decision could have already been made before the mouse was moved), RT's longer than 4,000 ms as well as trials where participants failed to response, resulted in 11.39% of trials being excluded.

Significance testing. It was possible to significantly influence preference from increasing duration, with the face displayed for longer being chosen on the majority (59%) of trials. A one sample t-test was run on the data whereby the longer displayed face was chosen more often (M = 58.68, SD = 12.09) than the average of 50%, a statistically significant mean difference of 8.68, 95% CI [6.33 to 11.03], $t(103) = 7.32$, $p < .001$, $d = 0.72$. This large effect size is surprising and could potentially be due to having the faces displayed on screen until a response was made. This increased participants' exposure to the stimuli and increased duration for both stimuli.

Response times and initiation times. The RT's were similar in both conditions, although slightly longer in the short condition; A paired sample t-test was conducted to compare the two RT's, there was not a significant difference in the RT's for the longer duration face (M = 1681.02, SD = 439.87) and shorter duration face (M = 1728.37, SD = 438.74); 95% CI [-18.81 to 113.51], $t(103) = 1.42$, $p > 0.05$; $d = 0.14$.

Initiation times provides an indication of how engaged participants are with the task and quick initiation times demonstrate recordings of hand movements started early in the decision-making process. Although the average initiation time was higher in the short duration condition, a paired sample t-test was conducted to compare the two initiation times, there was not a significant difference in the initiation times for the longer duration face (M = 390, SD = 181) and shorter duration face (M = 417, SD = 195); 95% CI [-0.79 to 53.17], t (103) = 1.93, $p > 0.05$; $d = 0.19$.

Response trajectories. As shown in Figure 7.1 the trajectories for each condition were similar whether regardless of whether facial stimuli were presented for 900 ms or 300 ms. Figure 7.2 demonstrates that there is similar activity in both conditions.

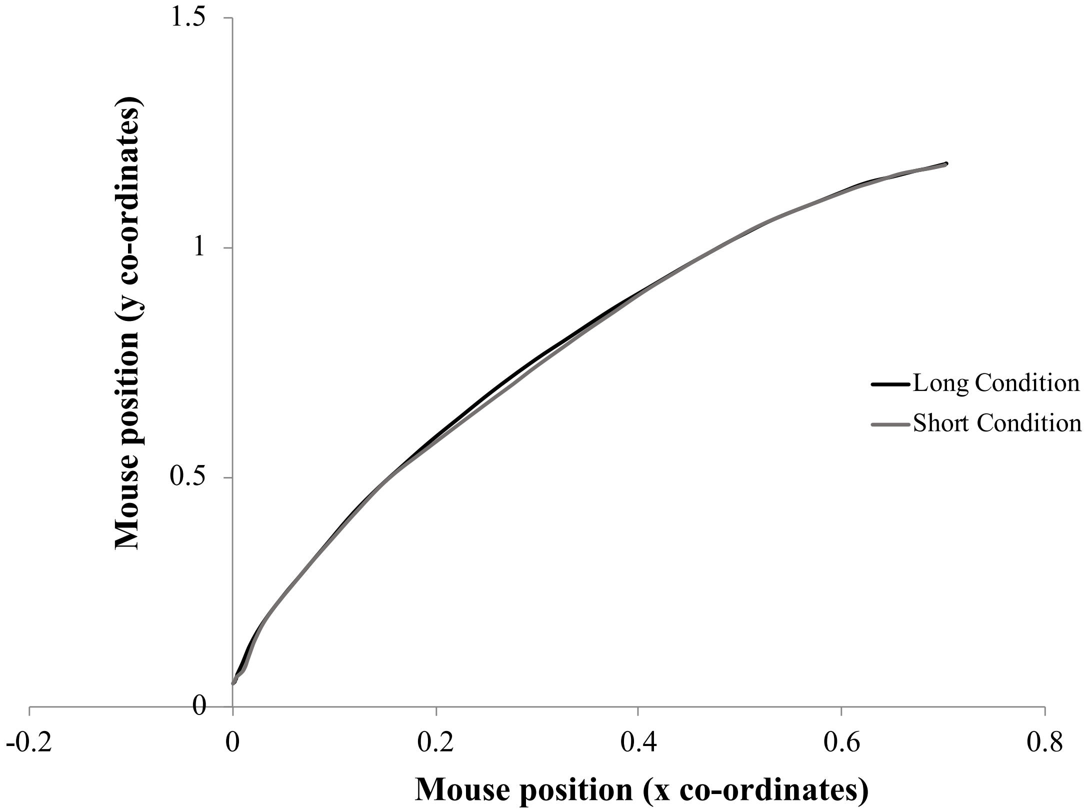
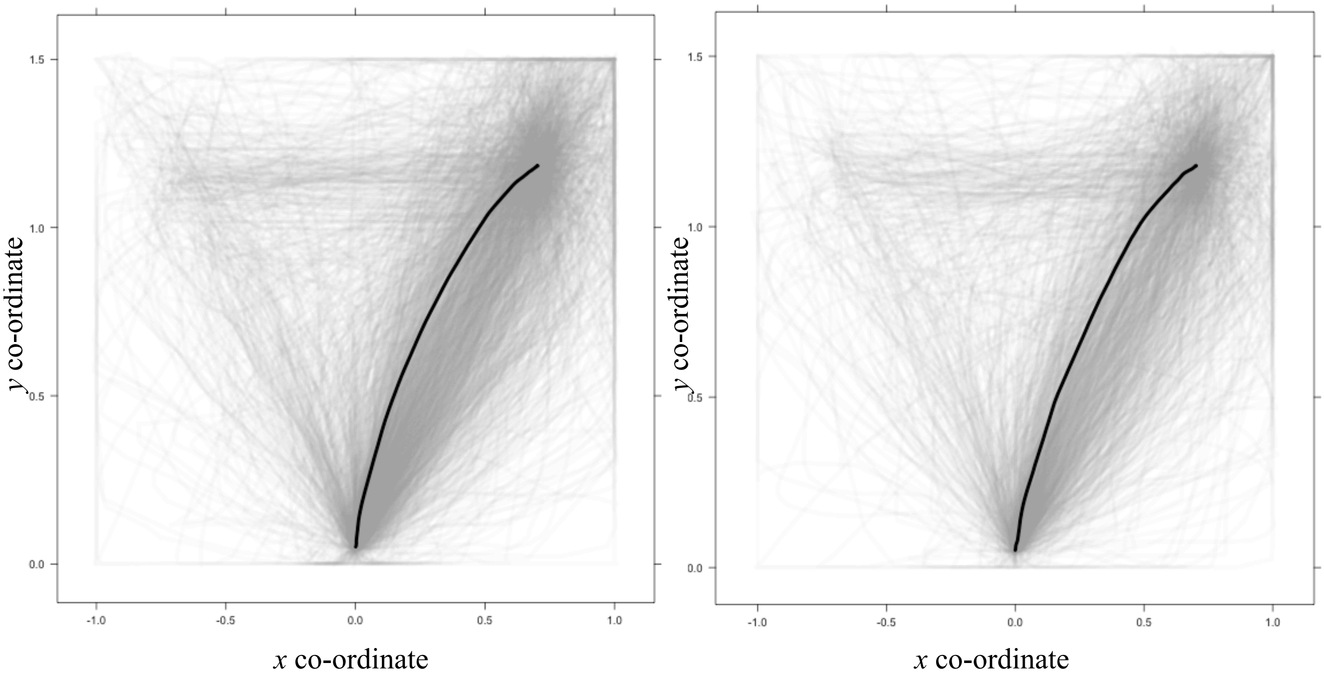


Figure 7.1. Response trajectories for the Long Condition (900 ms) and Short Condition (300 ms).



(a) Long condition (b) Short condition

Figure 7.2. All response trajectories for a trial, each line represents a response trajectory from the 'Start' button to response button for (a) the Long Condition (900 ms) and (b) the Short Condition (300 ms). The heavy black line represents the mean response trajectory in each condition.

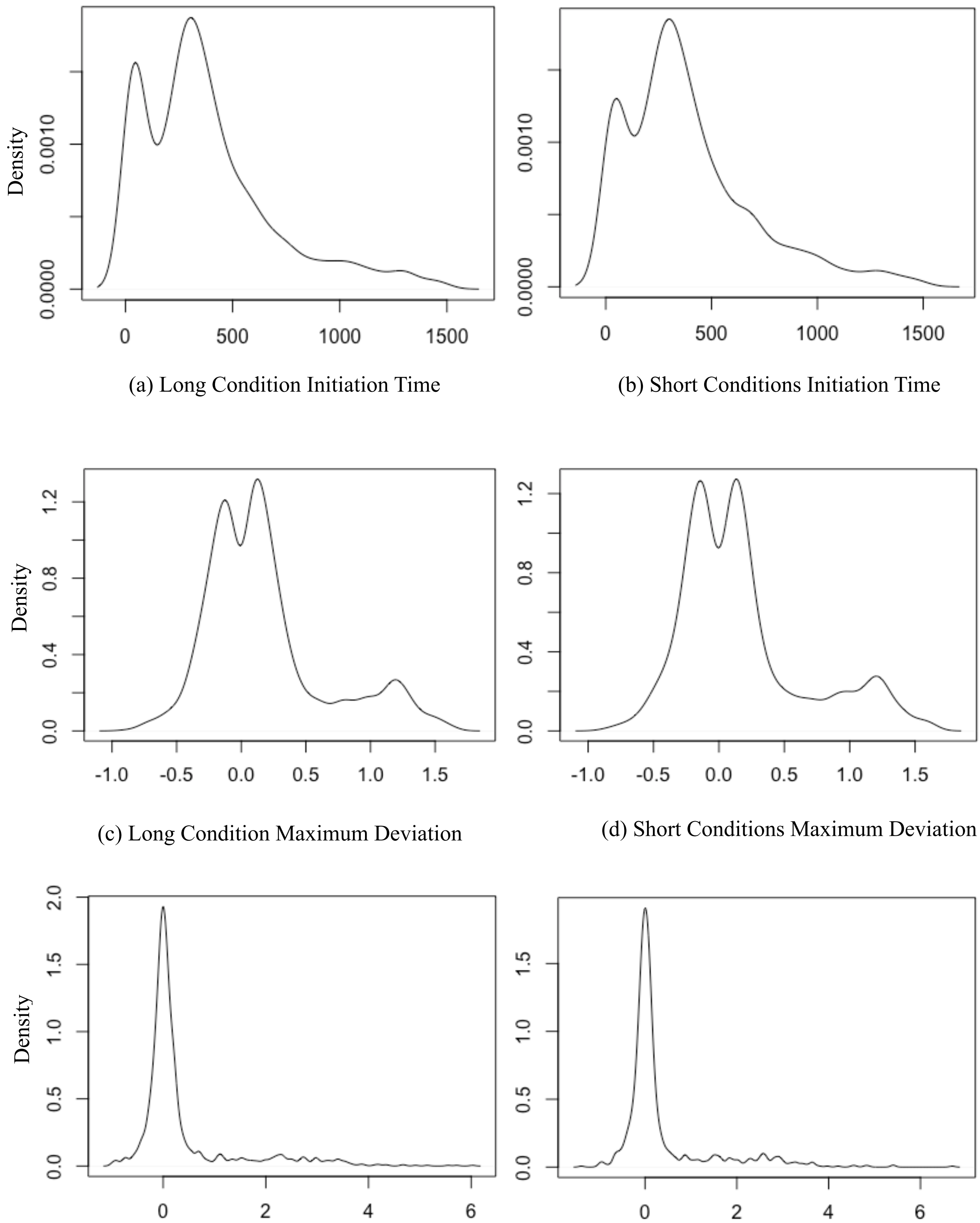
Maximum deviation and Area under the curve. As Figure 7.2 shows there is little difference in trajectories between conditions, the average maximum deviations were also similar in both conditions. A paired sample t-test was conducted to compare the two maximum deviations, there was not a significant difference for the longer duration face (M = 0.17, SD = 0.20) and shorter duration face (M = 0.18, SD = 0.21); 95% CI [-0.53 to 0.30], $t(103) = 0.56$, $p > 0.05$; $d = 0.05$. The average area under the curve was also similar. A paired sample t-test was also conducted to compare the two area under the curves, there was not a significant difference between the longer duration face (M = 0.39, SD = 0.42) and shorter duration face (M = 0.37, SD = 0.47), 95% CI [-0.11 to 0.78] t (103) = 2.88, $p > 0.05$; $d = 0.28$.

Distributions. As shown in Figure 7.3, the majority of initiations occurred within the first 500 ms in both conditions as shown below. However, there are two peaks in initiation times within the first 500 ms, with participants either responding almost immediately or nearer 500 ms. This was also confirmed by Hartigans' dip test, for the Long condition, $D = 0.03$, $p <$

0.01 and for the Short condition $D = 0.03$, $p < 0.05$. As mentioned in previous chapters, bimodality in initiation times could simply reflect the design of the MouseTracker software, given this appears across all conditions it is therefore unlikely to be driven by the conditions themselves.

As shown in the distribution plots for each maximum deviation (Figure 7.3), there was a small number of larger maximum deviations in the right tail of both conditions. In the left tail, there was evidence of an additional peak (which as stated previously may relate to hand kinematics). Bimodality was confirmed by Hartigans' dip test, for the Long condition, $D = 0.03$, $p < 0.01$ and for the Short condition $D = 0.03$, $p < 0.05$. This bimodality is not however shown in the area under the curve for either condition as shown in the distribution plots below (Figure 7.3).

In summary, whilst it is possible to significantly increase the preference for the longer duration face, as found in previous experiments this impact is relatively small (59%). Between the long duration and short duration conditions, there appears to be little difference between variables such as initiation times, responses times and little difference in the response trajectories, maximum deviation or area under the curve. It is possible that the lack of differences between conditions was due to the faces being repeatedly displayed multiple times, thus participants may have reached a decision before the responses were displayed.



(a) Long Condition Initiation Time

(b) Short Conditions Initiation Time

(c) Long Condition Maximum Deviation

(d) Short Conditions Maximum Deviation

(e) Long Condition Area under the curve

(f) Short Conditions Area under the curve

Figure 7.3. Distributions across the Long and Short condition for initiation times, maximum deviation and area under the curve.

7.4 Introduction: Experiment 7.2

In order to reliably conclude that there was an effect for duration and participants had not already made up their minds by the time the responses were shown, a final study was undertaken whereby only the duration of the facial stimuli was manipulated and the response trajectories of participants were recorded whilst a decision was made. Each face only displayed once. As shown in Experiment 7.2, duration was the important part of the manipulation and repetition did not impact participants' choices so it is expected that reducing repetitions should still cause the face displayed for longer to be preferred.

7.5 Method: Experiment 7.2

Participants: Fifty-five participants took part in the experiment, 14 students from the University of Bristol completed the experiment for course credit and the remainder volunteered to participate. As noted in the previous priori calculation, 43 participants were required in total to have 80% power for detecting a small sized effect when employing the traditional .05 criterion of statistical significance (Faul, et al., 2007). A post hoc power analysis was conducted on a sample size of 55, cohen's *d* effect size of 0.39, and an alpha level of .05 which revealed the statistical power for this experiment was 0.89 for detecting a small effect (Faul, et al., 2007).

Materials and Stimuli. Images were either presented on a 21" 1,920 x 1,200 pixel computer monitor or 1,024 x 768 pixel laptop. The faces were identical to Experiment 6.2 and 7.1. The same pairings used for Experiment 3 were used in this experiment and again no rating phase was included. There were 14 male pairs and 13 female pairs.

Design and Procedure. Identical to Experiment 7.1 whether faces appeared on the left- or right-hand side of the screen was counterbalanced.

Participants initiated each trial by clicking on the start button which was located at the bottom centre of the screen, the faces then flashed alternatively on screen. Face A for 900 ms and Face B for 300 ms. Once both faces had appeared, each face would appear at the top hand corners of the screen and the participants were able to move their mouse and select which face they preferred. The experiment lasted approximately 3 minutes.

If participants did not respond after 750 ms they were told to move the mouse as soon as the responses appear. Due to a technical error, this reminder was missing when the experiment was run with students who participated for course credit. After 9,000 ms, a time out message appeared on screen and the trail ended.

7.6 Results: Experiment 7.2

Comparisons between data set with warning and data set without warning: As 14 participants did not receive a warning to move the mouse when they were inactive for the first 750 ms, a comparison of the data sets is necessary before the data sets can be combined. Before exclusions, the average number of times the long response was chosen was 55.25% in the data without warning, compared to 58.07% of times with a time warning. The average response time for the two data sets was higher in the group with no warning; an independent samples t-test was conducted and there was a significant difference in the RT's for the group without a warning (M = 1849 ms, SD = 694 ms) and group with a warning (M = 1294 ms, SD = 322 ms); 95% CI [279.78 to 830.33], $t(53) = 4.04$, $p < 0.01$; $d = 0.56$. However, the average initiation time for the data without warning and the data with a warning was similar; an independent samples t-test was conducted and there was not a significant difference in the initiation times for the group without a warning (M = 268 ms, SD = 162 ms) and group with a warning (M = 270 ms, SD = 175 ms); 95% CI [-109.30 to 103.96], $t(53) = 0.50$, $p > 0.05$; $d = 0.01$.

After exclusions, the average number of times the long response was chosen was 55.30% of times in data without warning, compared to 57.11% of times with a time warning. After exclusions the average response time for both data sets were similar; an independent samples t-test was conducted and there was no longer a significant difference in the RT's for the group without a warning (M = 1269 ms, SD = 165 ms) and group with a warning (M = 1183 ms, SD = 180 ms); 95% CI [-39.11 to 211.83], $t(47) = 1.39$, $p < 0.05$; $d = 0.20$. After exclusions, the average initiation time for the data without warning and the data with a warning was similar; an independent samples t-test was conducted and there was no significant difference in the initiation times for the group without a warning (M = 179, SD = 101) and group with a warning (M = 228 ms, SD = 126 ms); 95% CI [-135.38 to 37.79], $t(47) = 1.13$, $p < 0.05$; $d = 0.16$. To conclude, there does not appear to be any significant differences between the data provided by those with a warning and those without, therefore, the following analysis will combine both data sets.

Exclusion criteria. Using the same exclusion criteria as Experiment 7.1 resulted in 16.53% of trials being excluded. Six participants were then removed completely as over 50% of the trials had already been excluded.

Significance testing. It was possible to significantly influence preference from increasing duration with the face displayed for longer being chosen in the majority (56.71%) of trials; a one sample t-test was run on the combined data whereby the long displayed face was chosen more often (M = 56.71, SD = 10.66) than the average of 50%, a statistically significant mean difference of 6.71, 95% CI [3.64 to 9.77], $t(48) = 4.40$, $p < 0.01$, $d = 0.63$.

To ensure the exclusions made did not bias the results a one sample t-test was run on the combined data pre exclusions whereby the longer displayed face was also chosen more often (M = 57.35, SD = 9.81) than the average of 50%, a statistically significant mean difference of 7.35, 95% CI [4.70 to 10.00], $t(54) = 5.56$, $p < 0.01$, d = 0 .08.

Initiation time and response times. The RT's were similar in both conditions; a paired sample t-test demonstrated there was not a significant difference in the RT's for the longer duration face (M = 1195 ms, SD = 187 ms) and shorter duration face (M = 1210 ms, SD = 193 ms); 95% CI [-48.04 to 18.95], $t(48) = 0.87$, $p > 0.05$, $d = 0.13$. The average initiation time was also similar in both conditions; a paired sample t-test showed was conducted to compare the two initiation times, there was no significant difference in the initiation times for the longer duration face (M = 219 ms, SD = 136 ms) and shorter duration face (M = 218 ms, SD = 129 ms); 95% CI [-27.44 to 30.51], $t(48) = 0.11$, $p > 0.05$, $d = 0.02$.

Response trajectories. As shown in Figure 7.4 the average trajectory for the short condition was more direct at the start mouse movements. Figure 7.5 demonstrates that there is similar activity in both conditions. Note that due to more participants choosing the face displayed in the longer condition, there are more response trajectories plotted in this condition.

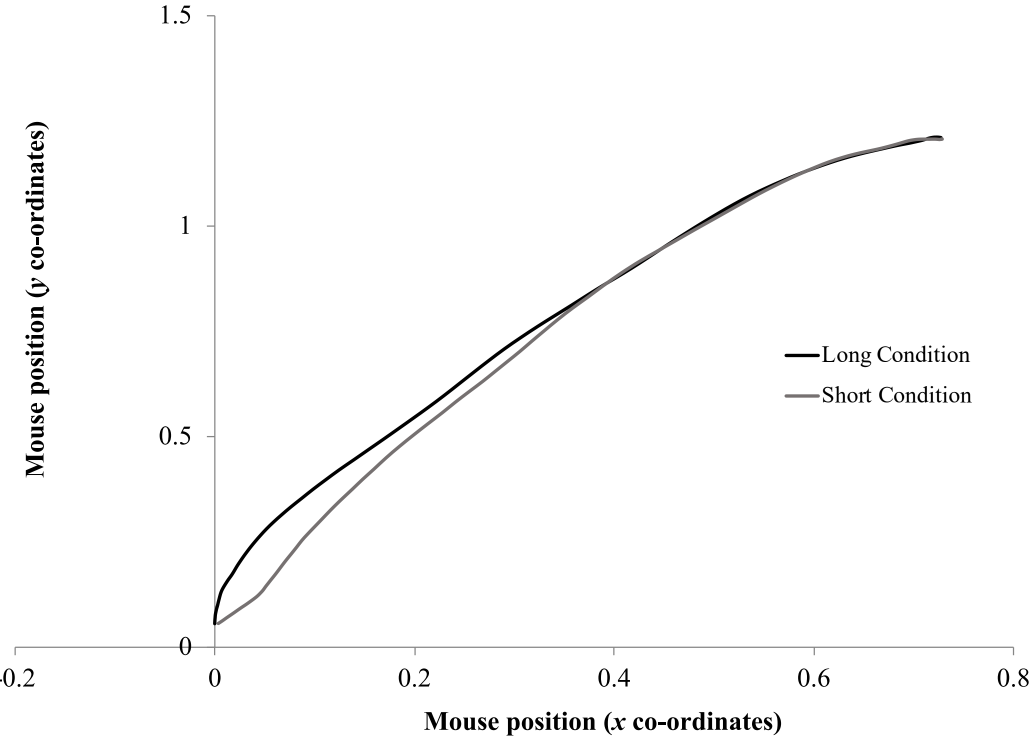


Figure 7.4. Response trajectories for the Long Condition (900 ms) and Short Condition (300 ms) when faces were not repeated on either side.

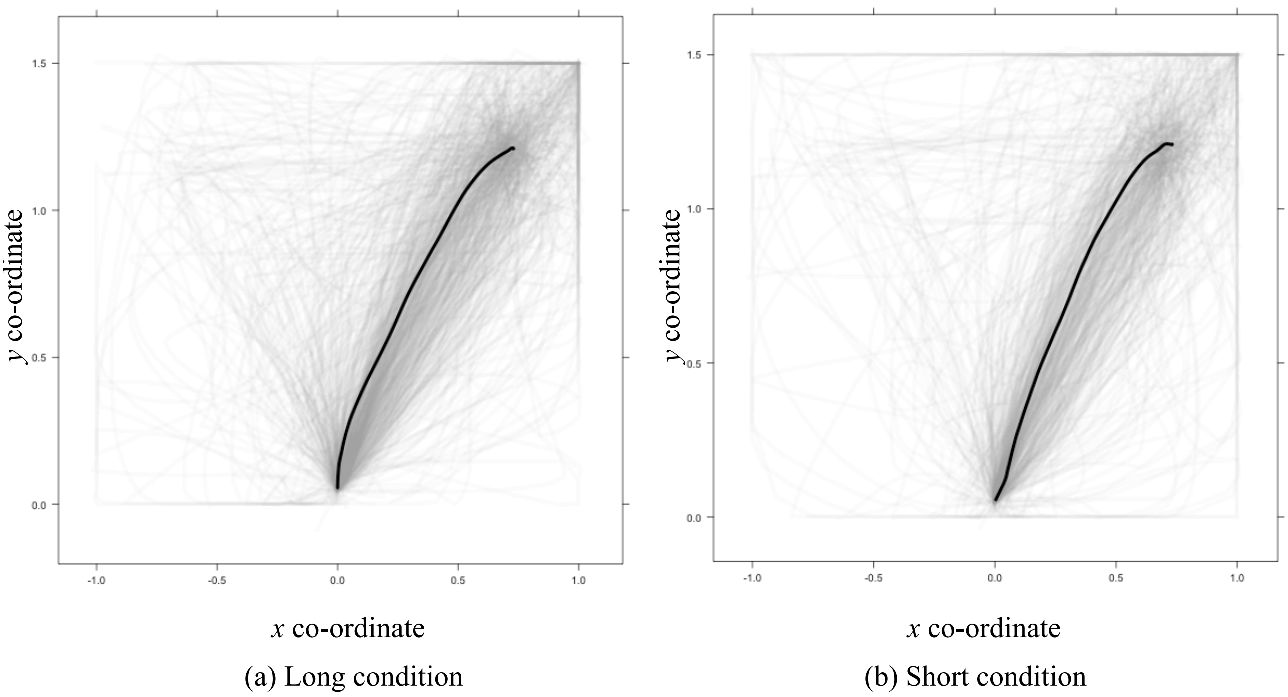


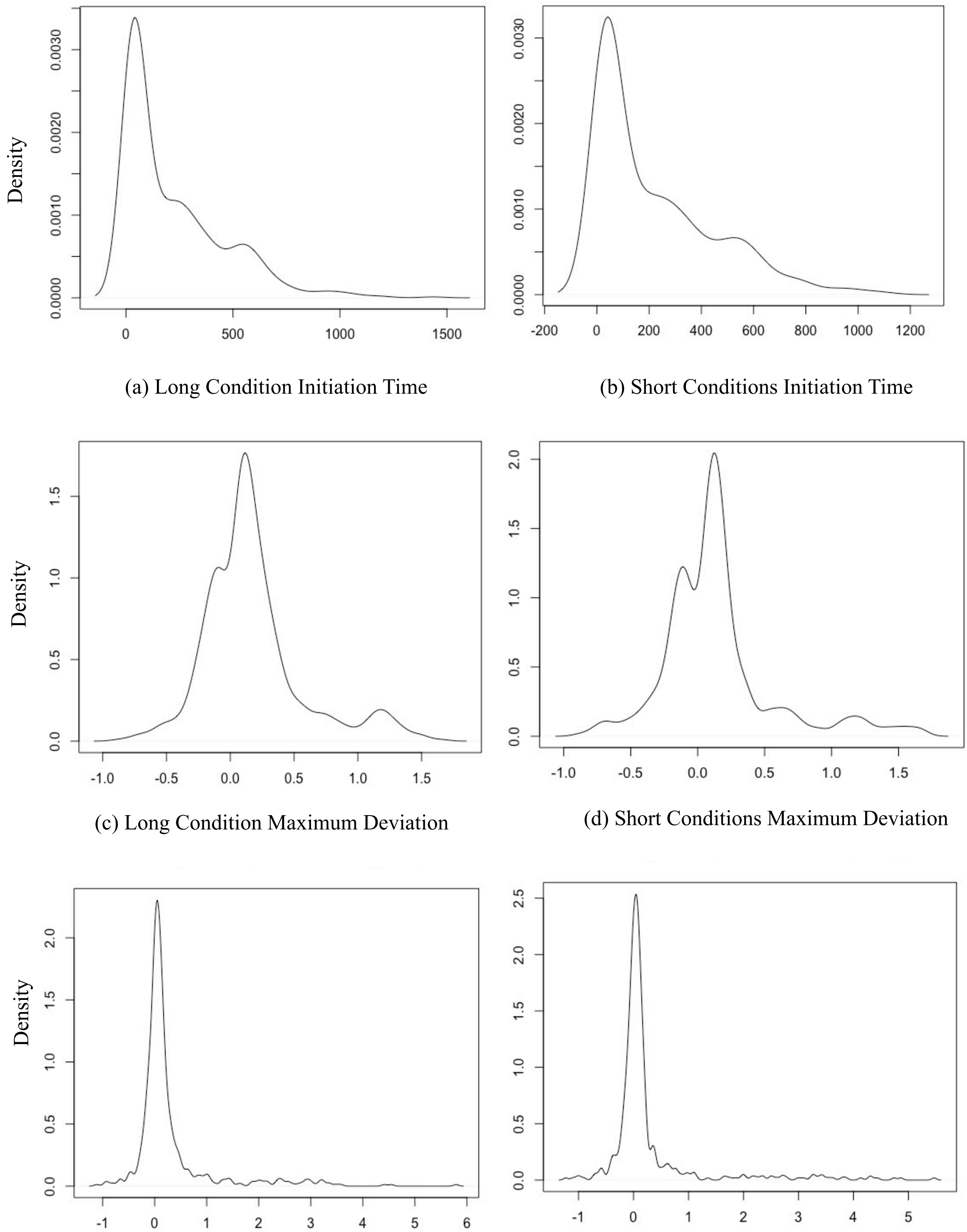
Figure 7.5. All response trajectories for a trial, each line represents a response trajectory from the ‘Start’ button to response button for (a) the Long Condition (900 ms) and (b) the Short Condition (300 ms). The heavy black line represents the mean response trajectory in each condition.

Maximum deviation and Area under the curve. Whilst there were differences during the initial movements made in each condition, the average maximum deviation was similar in both conditions; a paired sample t-test demonstrated there was no significant difference in the maximum deviation for the longer duration face (M = 0.18, SD = 0.15) and shorter duration face (M = 0.15, SD = 0.15); 95% CI [-0.01 to 0.09], $t(48) = 1.52$, $p > 0.05$, $d = 0.22$.

The average area under the curve was also similar, a paired sample -test demonstrated there was not a significant difference in the maximum deviation for the longer duration face (M = 0.31, SD = 0.31) and shorter duration face (M = 0.29, SD = 0.36); 95% CI [-0.09 to 0.11], $t(48) = 0.\ 25$, $p > 0.05$, $d = 0.04$.

Distributions. As shown in Figure 7.6, the majority of initiations occurred within the first 200 ms in both conditions as shown below. However, there are two peaks in initiation times within the first 500 ms, with participants either responding almost immediately or nearer 500 ms. This was also confirmed by Hartigans'' dip test, for the Long condition, D =0.04, $p <$ 0.01 and for the Short condition $D = 0.04$, $p < 0.05$. As mentioned in previous chapters, bimodality in initiation times could simply reflect the design of the MouseTracker software, given this appears across all conditions it is therefore unlikely to be driven by the conditions themselves.

As shown in Figure 7.6, the maximum deviation density plots for each condition participants demonstrated a slight bimodal tendency in each condition. This is also shown in the Hartigans'' dip test for unimodality / multimodality which gives values less than 0.05 in both conditions. For the long condition $D = 0.017$, $p = 0.041$ and for the short condition, D = 0.026, $p = 0.018$. This bimodality is not however shown in the area under the curve as shown in the distribution plots below (Figure 7.6).



(a) Long Condition Initiation Time

(b) Short Conditions Initiation Time

(c) Long Condition Maximum Deviation

(d) Short Conditions Maximum Deviation

(e) Long Condition Area under the curve

(f) Short Conditions Area under the curve

Figure 7.6. Distributions across the Long and Short condition for initiation times, maximum deviation and area under the curve.

In summary, whilst it is possible to significantly increase the preference for the longer duration face as found in the previous experiments this impact is relatively small (57%). Similar to the results of Experiment 3, there appears to be little difference between the long duration and short duration conditions for variables such as initiation times, responses times, maximum deviation or area under the curve. However, response trajectories do indicate when choosing the face which was displayed for the shortest amount of time, participants initial movements were more direct. As predicted by the findings from Chapter 6 removing the repetition element of Shimojo et al (2003)'s paradigm did not impact the ability to increase preference for longer duration faces.

7.7 Discussion

The results from these two experiments demonstrate that it is possible to manipulate preferences for facial imagery by presenting one face for longer. This is consistent with the previous experiments detailed here and previous research (Shimojo et al., 2003; Nittono and Wada, 2009; Bird et al., 2012). Similar to these previous experiments this effect is relatively small (59% and 57%).

The lack of differences between the two conditions for initiation times, RT's, maximum deviation and area under the curve indicate that presenting a face for longer did not result in vastly different responses. This may be because computer generated faces were used so participants were not invested in the task or it may simply reflect that this experimental design, which usually measured the percentage of times a face was chosen and did not usually measure RT's, did not require the extra analyses provided by mouse tracking.

Plotting the response trajectories indicated that when a face was displayed for longer participants response trajectories were indirect at the start of the mouse movements compared to the other condition. This may reflect a lack of certainty on the part of the participant, if increasing duration changed a participant's preference it is reasonable to expect the trajectories to reflect some hesitation or conflict. However, given these differences did not significantly affect maximum deviation or area under the curve it is unlikely these differences were large.

Whilst this experiment did not directly test the Gaze cascade hypothesis with the mere exposure effect, previous research has indicated the most likely explanation for the increase in preference for the longer presented face is likely to be due to the mere exposure effect (Zajonc, 1968) which states that repeated exposure to a stimulus increases preference.

Similarly, Shimojo et al. (2003) original paradigm suggested it was necessary for eye movements to be made and faces to be repeatedly shown on either side of the screen. However, Experiment 7.2 indicates that repetition is not required for the effect to be found and duration appears to be key. This also provides further support to the results in Experiment 6.2, which indicated duration was an important factor influencing preference.

Overall, mouse tracking did not add any additional information to the data analysis. However, due to the intuitive nature of the experimental design in mouse tracking, it was possible to test large numbers of participants at the same time without having to give any training or individual coaching.

Chapter 8 General discussion

8.1 Chapter Summary

This chapter will summarise the role of mouse tracking as a low-cost alternative methodology in relation to the four visual attention empirical chapters and two mere exposure empirical chapters. The practical and theoretical implications from the individual chapters of this thesis will be discussed before finally, the potential directions for future work and the main conclusions are considered.

8.2 Summary of Empirical Chapters

8.2.1 Chapter 2: Using Mouse Tracking to replicate the Spatial Orientating Paradigm

Typical psychophysical experiments use RTs and accuracy rates to measure performance on visual attention tasks. In order to address whether mouse tracking could be a useful tool in studying visual attention, Chapter 2 provided a simple replication of Posner's (1980) Spatial Orientating Paradigm whereby participants had to identify which side of the screen the target appeared. Endogenous attention was either manipulated either towards a target location (valid cues), away from the target location (invalid cues) or in neither direction (neutral cues). In order to measure participants performance as well as recording RT's, the additional measurements provided by mouse tracking were explored in more depth such as initiation times, response trajectories, maximum deviation, area under the curve and distributional analyses.

Overall, the results clearly demonstrated that when spatial attention is directed to the correct location (valid cues) participants performance is significantly better than when attention is directed to the incorrect location (invalid cues). Specifically, RTs indicated that participants moved quickest in the valid condition and slowest in the invalid condition. However, there was no significant difference between neutral cues and invalid cues. The mouse tracking analysis was able to provide further insight into the on-line process that occurred. In the valid cue condition, participants were able to move directly and quickly to the correct response, as indicated by the response trajectories and corresponding maximum deviation and area under the curve. In the neutral cue condition, whilst RTs appeared to be longer for the neutral condition, the mouse tracking data (initiation times and a bimodal distribution analysis of initiation times) illustrated that this was likely to be because participants hesitated at the start of the trial. In the invalid cue condition, RTs were longer because participants moved towards the incorrect response before correcting response movements and selecting the correct response.

8.2.2 Chapter 3: Mouse tracking and visual processing with distractors

In order to investigate whether mouse tracking could be used to investigate visual attention in target discrimination tasks. Performance between a task without distractors (simple condition) was compared to a task with distractors (distractor condition).

The results from the experiment replicated previous findings that performance at target discrimination was better when distractors are not present. Not only were RT's slower and error rates higher when distractors were present, the mouse tracking data demonstrated that participants were more likely to move towards the incorrect response as reflected in indirect response trajectories and significant differences in maximum deviation and area under the curve. A pattern that was not a result of averaging across participants but was consistent for each participant. The analysis also demonstrated that the response button relation to a targets orientation and location was an important methodological consideration. Mouse tracking was able to provide this information without any of the problems associated with SAT procedures such as the task being in an unnatural format, training required, secondary cognitive load, excessive trials or loss of data.

8.2.3 Chapter 4: Mouse tracking and visual processing with cues

In order to continue to investigate the role of visual attention on target discrimination tasks, an experiment was conducted that manipulated attentional demands by increasing the number of targets whilst simultaneously decreasing the number of cues. A mouse tracking analysis was carried out on 1) the effect of increasing the number of targets/decreasing the number of distractors (against a non-informative central cue), 2) the effect of increasing the number of cues, and 3) a comparison of a non-informative neutral cue with a single informative cue. The results demonstrated that increasing the number of targets gradually improved performance at target discrimination. However, increasing the number of cues only improved target discrimination performance in terms of RTs and initiation times when three or four cues were used in the four-target condition. It therefore appeared overall participants were ignoring cues as was demonstrated in the third analysis where an informative cue was compared to a non-informative cue.

8.2.4 Chapter 5: Hemifield effects in visual discrimination tasks

Previous research has demonstrated that each visual hemifield has a different attentional capacity and it may be advantageous to present stimuli across both hemifields to utilise both attentional resources (Alvarez & Cavanaugh, 2005). Specifically, in visual search tasks Reardon et al. (2009) found a hemifield advantage only when attentional demands were increased by the presence of distractors. In order to study the hemifield effects in visual discrimination tasks, data from Experiment 4 when distractors were present were compared with additional data when distractors were absent. However, the results showed no hemifield effect when distractors were present. This could be due to a lack of power because there were not many relevant trials and second, partcipants were part of a larger study which may have confounded the results and participants would have become more practised at the visual search task. Contrary to Reardon et al. (2008) mouse tracking data demonstrated a hemifield advantage when distractors were not present. This suggests even without additional attentional demands such as distractors it might be beneficial to split visual attention across hemifields.

8.2.4 Chapter 6: A replication of gaze manipulation and preference

Rather than using motor activities to record cognitive processes, this chapter looked at whether it was possible to manipulate motor activities to influence cognitive processes. The first aim of the study was to manipulate the finding by Shimojo, Simion, Shimojo, and Scheier, (2003) that by manipulating gaze (eye movements) it was possible to influence preference. Whilst the first experiment failed to replicate the finding, this may have been due to participants not engaging in the task, as demonstrated in low attractiveness ratings given to all stimuli. The second part of the chapter reviewed other failed replications of the finding, specifically a replication by Bird, Lauwereyns, and Crawford, (2012) which found that changes in preferences were not driven by eye movements but by the mere exposure effect. First, in order to investigate how the mere exposure effect influenced preference a second experiment was conducted which manipulated duration, repetition and both duration and repetition. Second, in order to increase attractiveness ratings and replicate the finding that increased exposure influenced preference different facial stimuli were used. The findings suggested that only duration had a small but significant influence on preference and the mere exposure effect was not driven by repeated sampling but by the duration of the facial stimuli.

8.2.5 Chapter 7: Mouse tracking duration and repetition effects on preferences

In order to address the lack of power in the previous experiment, the two experiments in this chapter tested a much larger number of participants. Rather than solely measuring differences in the percentage of faces chosen these experiments also used mouse tracking to see if it could provide any additional analyses. The first experiment demonstrated that, consistent with previous findings, increasing the duration of one face had a small but significant influence on preference. However, no differences were found in the mouse tracking analysis. It is possible that the lack of differences was due to participants determining their response during the time the faces were repeatedly shown on screen. Thus, when they moved their mouse to respond they had already made a decision. To address this in a second experiment, facial stimuli were only presented once and display duration was manipulated. Consistent with previous findings, a small but significant effect was found but there were no differences in the mouse tracking analyses. Whilst no differences were found, the experimental design of the mouse tracking paradigm allowed for large numbers of participants to be easily tested at the same time without additional training.

8.3 Methodological Implications

Whilst typical measures of psychophysical tasks include measurements of RTs and accuracy rates, these measures are only able to depict the end state of a process. One common concern of these particular measures is that they can be easily confounded by the speed-accuracy trade off where greater speeds come at the cost of greater errors and slower speeds result in fewer errors. Whilst ideally the participant tries to maximise performance by offsetting speed and accuracy it is not always possible to determine where along the speed-accuracy trade-off continuum each participant is responding. Instead many studies have used a response-signal SAT paradigm, whereby on each trial a participant may only respond when they receive a signal to do so. By manipulating time of the signal onset and plotting accuracy as a function of time it is possible to quantify the temporal dynamics of information accumulation on a task.

However, even using a SAT paradigm has a number of drawbacks. It is unnatural to limit responses to a signal and therefore participants require a substantial amount of training, and even after training a significant amount of data is lost. Monitoring a response also creates a secondary load on participants which can also result in loss of data when participants fail to respond. Alternatively, mouse tracking is an easy, low cost methodology which participants find intuitive and require no training.

In this thesis mouse tracking was successfully used to replicate the Spatial Orientating Paradigm (Posner, 1980) in Chapter 2 and the effect of distractors in conjunctive visual tasks on target discrimination abilities in Chapter 3. It was also then possible to explore the effect of increasing the number of targets and increasing the number of cues in visual search discrimination tasks in Chapter 4, and potential hemifield effects in Chapter 5. Overall mouse tracking appears to provide a suitable methodology for tasks when typical measures include RTs. When mouse tracking was used to investigate the mere exposure effect on facial preference, a task which usually only measures the percentage of times a response option was chosen, mouse tracking did not demonstrate any discernible differences (Chapter 7), suggesting a judgement had already been made before the response was initiated.

However, the analyses over the course of the chapters have raised some considerations. By averaging across response trajectories, it is possible that an overall curved trajectory could be concealing that in some trial's participants move directly towards the correct alternative whereas in other trials participants move towards the incorrect response. The distributions of the measures have therefore been examined. When analysing the distributions of initiation times, it was found in Chapter 3, Chapter 4, Chapter 5 and Chapter 7 that there were two peaks of initiation times, with the majority of responses occurring in the first 100 ms and a second smaller peak occurring between 300 – 500 ms. This appeared across all conditions and therefore did not appear to be driven by manipulations made in the conditions themselves. Instead it appeared to reflect the design of the MouseTracker software which starts recording initiation times from a nudge or regrip of a mouse. Future studies may want to consider a more complicated definition of an initial movement, as with determining when a saccade is being made in eye tracking.

Second, analyses of the distribution of maximum deviation, also demonstrated bimodality that was not driven by differences between the conditions themselves. In Chapter 3, Chapter 4, Chapter 5, Chapter 6 and Chapter 7 the left tail of the maximum deviation distribution formed a second peak with larger amounts of negative maximum deviation values. This appeared across all conditions and did not appear to be the result of differences in the condition. Instead it is possible these resulted in differences in hand kinematics; whereby movement in the hand towards the thumb side of the forearm (radial deviation of wrist) has more degrees of freedom than movement towards the little finger (ulnar deviation of the wrist; Holzbaur, Murray & Delp, 2005). When the correct answer is on the right-hand side these movements towards the left (negative MD) may become more frequent.

The use of mouse tracking should also consider that participants are generally more aware of the mouse movements they are making, than they are when making eye movements, thus unlike eye movements they are unable to provide a measure of concealed attentional shifts. It is also important to arrange the stimuli so that the maximum response trajectory can be created from the onset of the trial until selection, this may limit the visual display presented to participants; for example, response buttons cannot be placed above the starting point (Magnuson, 2005).

Overall, whilst mouse tracking cannot always fully track online response dynamics as they unfold over time, in some circumstances a decision has already been made, the use of mouse tracking in this thesis was successful in providing further insight into response dynamics beyond alternative end state measures such as RT's.

8.4 Theoretical Implications

The experiment in Chapters 3 demonstrates that, compared to when distractors are not present, the addition of conjunctive distractors to a visual search task hinders participants performance at discriminating the orientation of a target. These findings are generally no longer applied to a serial/parallel dichotomy or pre-attentive/attentive stage theory such as Feature Integration Theory (Treisman & Gelade, 1980). Instead alternative theories suggest that participants accumulate information until a decision threshold is reached. Signal detection theories suggest that when distractors are included, the noise between the target and alternative options are increased and the target may be confused with the distractor. The mouse tracking data demonstrated that there were higher error rates and increased response trajectories towards the alternative response, however, the reversals in movements along the x-axis were not significantly different. This suggests that confusability is not the sole reason for distractors causing difficulties in visual search tasks and simply including distractors which are similar to the target makes it harder to locate the target to perform the discrimination task (Duncan & Humphreys, 1989).

Contrary to Duncan and Humphreys' Similarity Theory (1989) which states that attention is drawn to an object and not locations, the location of the target in relation to the response button and orientation of the target impacted response dynamics. It is possible that this occurred because participants focused on the response buttons. This has two theoretical implications; first, it suggests participants use top down processes in visual search tasks as participants were already considering what response to make. Second, eccentricity effects are implicated; eccentricity effects suggest targets located nearer fixation are found more easily than those presented in the periphery.

The experiment from Chapter 4 indicated that increasing the number of targets and decreasing the number of distractors aided participants ability to discriminate the orientation of a target. From an information accumulation viewpoint, it would appear that increasing the number of targets allowed participants to utilise the additional information provided by increasing the number of targets to reach a threshold quicker. Unlike Chapter 3, this was not a set size manipulation as attention always had to be split between four items. Duncan and Humphreys' Similarity Theory (1989) would suggest that participants are able to group similar targets together, thus attention is only split between two groups. However, unlike this experiment, previous studies have not found a gradual cost of adding additional homogenous items but have found gradual differences when using heterogenous stimuli. It is possible that the gradual increase in performance occurred because this experiment used two types of stimuli, homogenous targets and heterogenous distractors.

Overall, increasing the number of cues did not consistently increase the performance in visual discrimination. It is possible that participants learnt to ignore cues even though they were always valid, but instead relied on a global accumulation of information from the whole array of stimuli. Although performance differences were found in the four-target condition, whereby increasing the number of cues from one/two cues to three/four cues impacted task performance especially in terms of initiation times. The results from Chapter 5 which found hemifield effects when distractors were not present, suggest that one potential explanation could be that this was due to the three/four cues including more trials that involve both visual hemifields.

Although the embodied cognition viewpoint suggests that action can influence cognition, Chapters 6 and Chapters 7 were unable to address this. The findings by Shimojo et al. (2003) which suggested manipulating gaze could influence preference appeared to be driven by the mere exposure effect and were not due to manipulating actions. The findings from Chapter 6 and Chapter 7 have two theoretical implications for the mere exposure hypothesis. First, it suggests that mere exposure can occur with conscious awareness and that the effect is actually stronger as duration (and potentially awareness, although this was not tested) is increased. Second, it suggests that the effects of mere exposure in this task did not occur as the result of repeated exposures but the result of increasing duration of a stimulus. The majority of mere exposure theories suggest repeated sampling is a key factor. For example, Zajonc et al. (2001) suggested repeated sampling coupled with a lack of negative response can create a positive conditioned response. The Perceptual Fluency Theory (Bornstein & D'Agostino, 1992, 1994) specifically states that increased sampling enhances processing ease, speed, and fluency of perception which can then be misattributed to liking.

Finally, the overall use of mouse tracking in this thesis challenges the traditional framework that cognitive processes and movement should be viewed as distinct and separate entities; the successful use of mouse tracking to reflect hesitation in responses and 'changes in mind' in this thesis supports the viewpoint that there is a link between action, perception and cognition (Freeman et al., 2011; Spivey et al., 2009).

8.5 Limitations, Future Directions and Conclusions

As demonstrated in Chapter 2, mouse tracking was able to successfully replicate previous findings from the Spatial Orientating Paradigm (Posner, 1980). However, the use of neutral cues was not significantly different from invalid cues in terms of RTs and it was not significantly different from valid cues in terms of response trajectories. Strictly speaking a neutral cue should represent a baseline whereby valid cues represent attentional benefits and invalid cues represent attentional costs. Also, the use of an arrow as a cue has been questioned (Bayliss, Pellegrino & Tipper, 2005). Due to the now commonplace arrows are in our environment it has been suggested that arrows cause attention to be involuntarily directed to an intended location (Chica et al, 2014). Not only could further research use alternative central cues, it would be interesting to address whether mouse tracking is equally as useful when investigating the role of exogenous orientation and the inhibition of return.

Whilst mouse tracking was able to successfully replicate the performance effects of including distractors in a visual search task whilst avoiding the limitations of the SAT paradigm in Chapter 3. The investigation into the use of targets and cues in Chapter 4 was hindered due to the complex experimental design. First, by ensuring set size effects remained constant by keeping four stimulus items on display at all times and manipulating the ratio of distractors and targets, it was not possible to isolate the effects of increasing targets from decreasing distractors. Second, participants potentially ignored cues because they mainly relied on targets/distractor display. In order to fully investigate the role of increasing targets and increasing cues in visual search tasks, future research should consider running experiments which isolate increasing targets, distractors and cues as separate manipulations.

This thesis was also unable to fully explore the role of potential hemifield effects. By running a reanalysis of Experiment 4 rather than a separate experiment, the number of eligible trials were relatively small, and any potential effects could have been confounded by other manipulations from Experiment 5 including practice effects. However, the results from Experiment 5 found a significant bilateral advantage before distractors were introduced which suggests that further replications with and without distractors would be worthwhile.

Finally, the thesis was able to demonstrate that motor responses reflected cognition, although, it was not able to address whether motor responses could influence cognition. Specifically, the mouse tracking analysis demonstrated that in terms of visual search participants are less able to discriminate a target's orientation when distractors are present and that increasing the ratio of target to distractor clearly aided discrimination. However, participants were less able to utilise cues. The replications of Shimojo et al. (2003) demonstrated the importance of duration in preference formation and allowed for multiple participants to be tested at one time. The main take-home message of this thesis is that mouse tracking is able to provide a low cost and intuitive methodology in which to investigate psychophysical tasks which traditionally use RTs as an end point measure, or a costly SAT procedure which may introduce a secondary task demand.

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